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CHAPTER 8

SAFETY AND TRAFFIC DESIGN

8.1 GENERAL

The purpose of this Chapter is to provide guidance for evaluating and developing highway safety alternatives to be incorporated into roadway and structural designs. This includes providing for the safe accommodation of traffic through construction work zones. The safety guidelines of any highway facility are primarily a reflection of the attitude of the administration responsible for the facility and the priority placed on the use of available funds. While the overall objective is maximum highway safety, environmental and economical restraints may prohibit achieving this goal. The designer must, therefore, ensure that the design provides the maximum safety enhancements for each dollar spent.

Agreements have been negotiated with most of the Federal agencies with significant public road mileage, and they have active programs to meet the applicable guidelines. These interagency agreements are described in Chapter 2. The FLH Divisions provide technical guidance to many of these agencies in the design and construction of their roads. In addition, they work to ensure that objectives of the *Highway Safety Guidelines* are accomplished.

8.1.1 SAFETY PHILOSOPHY

In support of the national goals set forth within the US Department of Transportation and the Federal Highway Administration, FLH is equally committed to reducing the number of deaths and serious injuries and improving the overall safety of transportation on Federal and Indian lands. Building on FLH's strong history in leading context sensitive engineering solutions, FLH will continue to evaluate individual projects and their appropriate functional classification to balance the FHWA transportation and safety mission with the land management and resource protection mission of the Federal Lands Managing Agencies (FLMAs). Appropriate safety applications are to be incorporated while respecting the resource impacts, historic and cultural values of the associated facility. This is to be achieved through a collaborative and cooperative effort between the FLH and the FLMAs. This includes:

- collection and reporting of accurate and timely crash data,
- implementation of Safety Management Systems and principles,
- early consideration of safety in all highway programs and projects,
- the identification and investigation of impacted hazardous locations and features and establishing countermeasures and priorities to address the identified or potential hazards,

- incorporating appropriate safety improvements in all FLH projects, and

- systematic upgrading of roadside features and elements will be designed to meet current nationally accepted standards for crashworthiness.

It is FLH's conviction that the respective statutory missions of FLH and partner agencies relating to enhancing safety are compatible. The FLH Vision is ''Creating the best transportation system in balance with the values of Federal and Tribal lands.'' This requires a unique effort to build a harmonic blend of the transportation access and environmental and resource protection elements of the respective agency missions. FLH is confident that its efforts in providing partnership, dedicated to addressing public safety concerns and historic and cultural issues, compliment the unique setting of the projects. The overall goal is to work cooperatively to integrate safety as a basic business principle in all activities jointly undertaken by the FLH and FLMAs.

Also refer to Chapter 9, Section 9.1.4 for additional information on the FLH highway design philosophy and Context Sensitive Solutions.

8.1.2 SAFETY DESIGN POLICY

New construction and reconstruction involves the application of appropriate policies, standards, and criteria in the design and construction of the facility (see Chapter 4, Section 4.4). The application of those guidelines virtually ensures a reasonable level of geometrics and safety. Even with their use, however, operational or roadside safety problems may still exist that will not be identified unless a safety analysis is performed.

It is Federal Lands Highway (FLH) policy that design standards apply to RRR projects in the same manner as new construction or reconstruction. However, because of the limited scope of RRR projects, reconstruction to meet full standards may not be possible and is generally not intended. When this occurs, the designer must identify the substandard features and analyze their potential effect on highway safety. The analysis and proposed mitigation are to be documented as discussed in Section 9.1.4.

8.1.3 ROADWAY SAFETY

A crash is seldom the result of a single cause. Typically, several influences affect the situation at any given time. These influences can be separated into three elements:

- the human,
- the vehicle, and
- the environment.

The environmental element includes the roadway and its surroundings. The designer can only control roadway elements and must make a judicious selection of the roadway geometrics, drainage, surface type and other related items to lessen the potential for crashes and/or reduce the severity should they occur. The ideal design applies appropriate guidelines over a section of roadway.

The designer should avoid discontinuities in the highway environment. Some examples include:

- abrupt changes in design speeds;
- short transitions in roadway cross section;
- short radius curves in a series of longer radius curves or at the end of a long tangent;
- changes from full to partial access control;
- roadway width constrictions (e.g., narrow bridges, other structures);
- intersections and pullouts with inadequate sight distances;
- hidden sag vertical curves and inadequate sight distance at crest vertical curves; and/or
- other inconsistencies in the roadway design.

Standardizing highway design features and traffic control devices reduces driver confusion and makes the task of driving easier. Through the use of these standard features, the driver learns what conditions to expect on a certain type of highway. The goal, if possible, is to design a highway so that a driver needs to make only one decision at a time. Multiple decisions confuse and distract a driver.

8.1.4 ROADSIDE SAFETY

Roadside safety design has become increasingly important as new technology has made possible improvements in the alignment, grade and roadway. When a vehicle leaves the roadway, any object in or near its path may become a contributing factor to the severity of the crash. The basic concept of a forgiving roadside is that of providing a clear recovery area where an errant vehicle can be redirected back to the roadway, stop safely or slow enough to mitigate the effects of the crash.

Consult the AASHTO *A Policy on Geometric Design of Highways and Streets* (*Green Book*) and the AASHTO *Roadside Design Guide* for guidance on appropriate clear recovery areas.

The designer must evaluate these requirements in conjunction with environmental, contextual and economic constraints to determine the acceptable clear zone for the traffic, speed and terrain of the project.

Potentially hazardous features located within the identified clear zone should be treated with one of the following options, which are listed in order of preference:

1. Remove the hazard.

2. Redesign the hazard so it can be traversed safely.

3. Relocate the hazard to a point where it is less likely to be struck, preferably outside the clear zone.

4. When a potential hazard remains in the clear zone, reduce the impact severity by using an appropriate breakaway device.

5. If the feature is potentially more hazardous than a barrier system that could shield it, consider installing a barrier system, a crash cushion or both.

6. If it is not feasible or practical to shield the hazard, delineate it.

8.2 GUIDANCE AND REFERENCES

The publications listed in this Section provided much of the fundamental source information used in the development of this Chapter. While this list is not all-inclusive, the publications listed will provide a designer with additional information to supplement this *Manual*:

1. *Roadside Design Guide*, AASHTO, Current Edition.

2. *Manual on Uniform Traffic Control Devices for Streets and Highways* (*MUTCD*), FHWA, Current Edition, with approved revisions.

3. *Standard Highway Signs*, FHWA, Current Edition.

4. *Traffic Engineering Handbook*, Institute of Transportation Engineers, Current Edition.

5. *Traffic Control Devices Handbook*, Institute of Transportation Engineers, Current Edition.

6. *Highway Capacity Manual*, Transportation Research Board, Current Edition.

7. *Highway Safety Design and Operations Guide*, AASHTO, 1997.

8. *Roadway Delineation Practices Handbook*, Report No. FHWA SA-93-001, 1994.

9. *Sign Manual*, US Department of the Interior, National Park Service, January 1988.

10. *Designing Safer Roads*, Special Report 214, Transportation Research Board, 1987.

11. *Safety Effectiveness of Highway Design Features*, Volumes I-VI, FHWA, 1992.

12. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, NCHRP Report No. 350, National Cooperative Highway Research Program, 1993.

13. *A Users Guide to Positive Guidance*, Report No. FHWA SA-90-017, September 1990.

14. *Local Highway Safety Studies Users Guide*, FHWA, Office of Highway Safety, July 1986.

15. *Identification of Hazardous Locations*, Report No. FHWA RD-77-87, FHWA, 1977.

16. *Synthesis of Safety Research Related to Traffic Control and Roadway Elements*, Volumes I and II, FHWA, 1982.

17. *Highway Safety Engineering Studies - Procedure Guide*, Report No. FHWA-TS-81-220, FHWA, 1981.

18. *Railroad-Highway Grade Crossing Handbook Users Guide*, Report No. FHWA-TS-86-216, FWHA, 2nd ed., September 1986.

19. *Alternate Approaches to Crash Costs Concepts,* FHWA, 1984.

20. *Roadside Safety Improvement Programs on Freeways — A Cost Effectiveness Approach,* Glennon, J.C., NCHRP 148, 1974.

8.3 INVESTIGATION PROCESS

The investigation process begins with the initial consideration and priority given to candidate projects for safety improvements. FLH Program projects involve the preservation or improvement of the facility and the enhancement of roadway safety.

The majority of FLH projects involve existing roadways. On existing highways, historical information relating to the highway's operation or safety should be analyzed. State DOT's generally have operational and safety records for the Federal system. Respective agencies frequently have data for routes on their systems. Unfortunately, on off-system county roads, the available data may be scarce. This is often due to the low-volume rural nature of the facility. As a result, many crashes on these facilities go unreported. Information retrieval systems may also be less developed for these roads. Good sources of information are law enforcement officials, local maintenance personnel, property owners, local businesses, mail carriers, school bus companies, etc. A drive through of the project, with a keen eye towards operational or safety problems, or potential problems, will often detect areas requiring special attention during design.

8.3.1 CRASH DATA

Many State highway agencies maintain computerized crash files. They can provide statistics regarding statewide rates for fatal, injury and property damage crashes as well as rates on specific routes. By comparing statistical trends in a given area of the State, the designer may detect clues to the basic causes or problems that should be addressed during design. For example, if a proposed FLH Program project were located in a portion of a State that has a higher than normal run-off-the-road crash rate, further analysis of the types of crashes (e.g., skidding) may be warranted.

The designer should review available crash reports to determine if any engineering features may have contributed to the problem. Law enforcement agencies can usually provide available crash reports. In the case of the National Park Service (NPS), each park maintains its own crash reports. In the past, the NPS used the same crash report forms for all crashes, and no attempt was made, until recently, to separate and file vehicle crash forms together. Recognition of this problem, however, has resulted in a service-wide effort to standardize the data input as well as to computerize it for easy retrieval. This effort, initiated in 1985, is known as the Service-wide Traffic Crash Reporting System (STARS). STARS will provide substantial information to the designer.

8.3.2 TRAFFIC SAFETY STUDIES

Traffic safety studies, when available, provide excellent references for evaluating safety and operational characteristics. The NPS has had traffic safety studies performed in many of their larger parks. The States or other agencies may also have such information available on their systems. While the content and form of traffic safety studies vary widely, they usually include an introduction that describes the goals and purpose of the study and defines the study area and project specifics.

8.4 SAFETY ANALYSIS AND DESIGN

The extent of appropriate safety enhancements on all projects can be determined by performing a safety analysis. A safety analysis consists of analyzing potentially hazardous features and locations; both the project's crash history and the list of potentially hazardous locations and features should be used during the project development process. At a minimum, review this information on each project where a design exception is requested. The project files should contain documentation of the safety analysis performed and any improvements or mitigations taken to enhance safety.

8.4.1 CRASH ANALYSIS

The amount of data available for analysis will vary from project-to-project as well as the level of detail and accuracy of the data. Therefore, the designer must determine on a case-by-case basis whether the data furnished for safety analysis purposes is satisfactory.

In some cases, the circumstances may indicate the need to evaluate crash reconstruction. This involves drawing inferences concerning the interactions of speed, position on the road, driver reaction, comprehension and obedience to traffic control devices and evasive tactics. Crash reconstruction uses basic engineering knowledge of vehicle motion analysis, force analysis and mechanical energy.

8.4.1.1 Crash History

The crash history for the project should be developed and analyzed to determine possible causes and to select appropriate safety enhancements. Where practical, crashes should be summarized by location, type, severity, contributing circumstances, environmental conditions and time period. This will help identify high-crash locations (HAL) and may indicate some spot safety deficiencies.

Depending on how crash information is filed, it may be necessary to record the information first and then group all crashes occurring at specific locations. This serves to identify HALs. Analysis of the types of crashes can suggest appropriate corrective action. The use of computer spread sheet programs will enhance the ability to evaluate this data.

Limited crash data are common on rural two-lane highways with low to moderate traffic volumes. Data generated from a small sampling can be misleading because they can be significantly influenced by small variances. The limited amount of this type of data often makes traditional methods of analysis difficult.

In addition to crash data analysis, a Road Safety Audit may be a more appropriate tool to use because it relies on an examination of an existing facility as well as reviewing crash data collected in the past. The procedure for performing this audit is described in Section 8.4.6, Roadway Safety Audits.

Special consideration should be given to analyzing crash data on RRR projects. To more fully understand the safety issues, analysis of RRR projects may often require the following special efforts:

- a study of individual crash reports including those just beyond the project termini,
- a review to relate crash data with field conditions, and
- Interviews with maintenance and/or police personnel. These interviews may reveal areas where operational problems or minor crashes occur, but are not documented.

Crash analysis study procedures involve determining the significance of the crash history and developing summaries of the crash characteristics. The project's crash rates and summaries are used to detect abnormal crash trends or patterns and to distinguish between correctable and non-correctable crashes. Analyses of these summaries are used to identify possible safety deficiencies of the existing facility.

When summarizing crash data for analysis purposes, adhere to the following criteria:

1. **Time Period**. Select a time period for the collection of the crash data (e.g., five years). The time period chosen should contain reasonably current information on traffic volumes, pavement condition and other site-related data. Past changes in the character of the facility (e.g., physical changes, roadside development) are accounted for when evaluating the crash activity.

2. **Direction of Traffic**. Examine crash data with respect to the direction the vehicles were traveling.

3. **Location**. Examine crash data with respect to location. Crashes occurring within an intersection area should be separated from those occurring outside the area of influence of the intersection. In addition, similar crash types occurring in differing situations should be recorded separately. For example, left-turn crashes into a driveway should not be included with left-turn crashes at an intersection. Collision diagrams may be useful in the analysis.

4. **Project Termini**. Examine the number of crashes and the crash rates within the project termini. A comparison of this data with statewide norms for similar facilities should provide a reasonable indication of the relative safety of the existing roadway.

5. **Compare Crash Statistics**. Summarize the crash data and compare it to typical statistics on similar facilities. A specific crash type categorizes patterns. The identification of crash-type patterns may be used to suggest possible causes. Consider the severity patterns to determine if particular roadway or roadside features have contributed to the overall severity of the crashes that have occurred.

6. **Contributing Circumstances**. Summarize the contributing circumstances portion of the crash report. This identifies possible crash causes noted by the investigating police officer. Contributing circumstances are categorized by:

   - human (driver) factors,
   - vehicle related factors, and
   - environmental factors.

   The contributing circumstances information is used to verify, add or delete possible causes developed by the crash summary by type procedure.

7. **Correctable Versus Non-Correctable Crashes**. The contributing circumstance data can be used to separate correctable and non-correctable crashes. In separating the crashes by these classifications, careful consideration should be made to ensure that the crashes are indeed non-correctable. Exhibit 8.4-A lists the contributing circumstances found on most crash reports and indicates if they are generally correctable or non-correctable through highway improvements.

8. **Environmental Conditions**. Summarize crashes by environmental conditions. This procedure identifies possible causes of safety deficiencies related to the existing condition of the roadway environment at the time of the crash. Typical classifications used in the analysis include lighting condition (i.e., daylight, dusk, dawn, dark) and roadway surface condition (i.e., dry, wet, snowy, icy, unknown). These summaries are compared to average or expected values for similar locations or areas to determine whether the occurrence of a specific environmental characteristic is greater or less than the expected value at the location.

8.4.1.2 Probable Causes and Safety Enhancement

Probable crash causes need to be defined once the crash patterns are identified. On-site or photolog reviews of field conditions of crash sites are used to reduce the list of possible causes identified on the crash history to the most probable causes. The probable causes identified can then be used as a basis for selecting appropriate safety enhancements to alleviate the safety deficiency. Exhibit 8.4-B is a listing of probable crash causes and possible safety enhancements. This list is not all-inclusive; however, it does provide a general list of possible crash causes as a function of crash patterns and appropriate safety enhancements.

8.4.2 EXISTING SITE CONDITIONS ANALYSIS

Hazardous locations or features on existing roadways may or may not be HALs. Many locations with narrow bridges, slippery pavement, rigid roadside obstacles or other potentially hazardous conditions have crash potential but may not yet have a crash history. Therefore, it is important to identify potentially hazardous locations or features in the development of projects. When crash history is not available, a project listing of potentially hazardous features and locations may be used to determine the need for safety enhancements.

Driver-Related	
Unsafe speed (C/N)	Sick (N)
Failed to yield right-of way (C/N)	Fell asleep (C/N)
Following too close (C/N)	Lost consciousness (N)
Improper passing (C)	Driver inattention (C/N)
Disregard traffic controls	Distraction (C/N)
Turning improperly (C/N)	Physical disability (N)
Alcohol involvement (C/N)	Drug involvement (C/N)
Vehicle-Related	
Brakes defective (C/N)	Tow hitch defective (N)
Headlights defective (C/N)	Overload or improper loaded (N)
Other lighting defects (C/N)	Oversize load on vehicle (N)
Steering failure (N)	Tire failure/inadequate (C/N)
Environment-Related	
Animal on roadway (C/N)	Holes/deep ruts/bump (C)
Glare (C/N)	Road under construction/maintenance (N)
View obstructed/limited (C/N)	Improperly marked vehicle(s) (C/N)
Debris in roadway (N)	Fixed objects (C)
Improper/nonworking traffic controls (C/N)	Slippery surface (C)
Shoulders defective (C)	Water ponding (C)
Roadside hazards	

Key:

(C) = Correctable
(N) = Non-correctable by safety enhancement
(C/N) = Either correctable or non-correctable depending on related circumstances

Exhibit 8.4-A CONTRIBUTING CIRCUMSTANCES

GENERAL CRASH PATTERN		
Crash Pattern	**Probable Cause**	**Safety Enhancement**
Run-off roadway	Slippery pavement	Improve skid resistance Provide adequate drainage Groove existing pavement
	Roadway design inadequate for traffic conditions	Widen lane/shoulders Relocate islands Provide proper superelevation Install/improve traffic barriers Improve alignment/grade Flatten slopes/ditches Provide escape ramp
	Poor delineation	Improve/install pavement markings Install roadside delineators Install advance warning signs
	Poor visibility	Improve roadway lighting Increase sign size
	Inadequate shoulder	Upgrade roadway shoulder
	Poor or confusing channelization	Improve channelization
Bridges	Alignment	Realign bridge/roadway Install advance warning signs Improve delineation/markings
	Narrow roadway	Widen structure Improve delineation/markings Install signing/signals
	Visibility	Remove obstruction Install advance warning signs Improve delineation and markings
	Vertical clearance	Rebuild structure/adjust roadway grade Install advance warning signs Improve delineation and markings Provide height restriction/warning
	Slippery surface (wet/icy)	Resurface deck Improve skid resistance Provide adequate drainage Provide special signing
	Rough surface	Resurface deck Rehabilitate joints Regrade approaches

Exhibit 8.4-B GENERAL CRASH PATTERNS

GENERAL CRASH PATTERN		
Crash Pattern	**Probable Cause**	**Safety Enhancement**
Bridges (Cont.)	Inadequate barrier system	Upgrade bridge rail Upgrade approach rail/terminals Upgrade bridge - approach rail connections Remove hazardous curb Improve delineation and markings
Overturn	Roadside features	Flatten slopes and ditches Relocate drainage facilities Extend culverts Provide traversable culvert end treatments Install/improve traffic barriers
	Inadequate shoulder	Widen lane/shoulder Upgrade shoulder surface Remove curbing/obstructions
	Pavement feature	Eliminate edge drop-off Improve superelevation/crown
Parked vehicles	Inadequate road design	Widen lane/shoulders
Fixed object	Obstructions in or too close to roadway	Remove/relocate obstacles Make drainage headwalls flush with side slope Install breakaway features to light poles, signposts, etc. Protect objects with guardrail Delineation/reflectorize safety hardware
	Inadequate lighting	Improve roadway lighting
	Inadequate pavement markings, signs, delineators, and guardrail	Install reflectorized pavement lines/raised markers Install reflectorized paint and/or reflectors on the obstruction Add special signing Upgrade barrier system
	Inadequate road design	Improve alignment/grade Provide proper superelevation Install warning signs/delineators Provide wider lanes
	Slippery surface	Improve skid resistance Provide adequate drainage Groove existing pavement
Sideswipe or head-on	Inadequate road design	Provide wider lanes Improve alignment/grade Provide passing lanes Provide roadside delineators Sign and mark unsafe passing areas
	Inadequate shoulders	Improve shoulders

Exhibit 8.4-B GENERAL CRASH PATTERNS
(Continued)

GENERAL CRASH PATTERN		
Crash Pattern	**Probable Cause**	**Safety Enhancement**
Sideswipe or head-on	Excessive vehicle speed	Install median devices
(Cont.)	Inadequate pavement markings	Install/improve centerline, lane lines and edge lines Install reflectorized markers
	Inadequate channelization	Install acceleration and deceleration lanes Improve/install channelization Provide turning bays
	Inadequate signing	Provide advance direction and warning signs Add illuminated name signs
Access-related	Left-turning vehicles	Install median devices Install-two-way left-turn lanes
	Improperly located driveway	Move driveway to side street Install curbing to define driveway locations Consolidate adjacent driveways
	Right-turning vehicles	Provide right-turn lanes Increase width of driveways Widen through lanes Increase curb radii
	Large volume of through traffic	Move driveway to side street Construct a local service road
	Large volume of driveway traffic	Signalize driveway Provide acceleration and deceleration lanes Channelize driveway
	Restricted sight distance	Remove obstructions
	Inadequate lighting	Improve street lighting
Intersection (signalized/ unsignalized) left turn, head-on, right angle, rear end	Large volume of left/right turns	Widen road Channelize intersection Install STOP signs Provide signal Increase curb radii
	Restricted sight distance	Remove sight obstruction Provide adequate channelization Provide left/right-turn lanes Install warning signs Install STOP signs Install signal Install advance markings to supplement signs Install STOP bars

Exhibit 8.4-B GENERAL CRASH PATTERNS
(Continued)

GENERAL CRASH PATTERN		
Crash Pattern	**Probable Cause**	**Safety Enhancement**
Intersection (signalized/ unsignalized) left turn, head-on, right angle, rear end (Cont.)	Slippery surface	Improve skid resistance Provide adequate drainage Groove pavement
	Large numbers of turning vehicles	Provide left- or right-turn lanes Increase curb radii Install signal
	Inadequate lighting	Improve roadway lighting
	Lack of adequate gaps	Provide signal Provide STOP signs
	Crossing pedestrians	Install/improve signing or marking of pedestrians crosswalks Install signal
	Large total intersection volume	Install signal Add traffic lane
	Excessive speed on approaches	Install rumble strips in travel lane
	Inadequate traffic control devices	Upgrade traffic control devices
	Poor visibility of signals	Install/improve advance warning signs Install overhead signals Install 300 mm (12 in) LED signal lenses Install visors/back plates Relocate signals Remove sight obstructions Add illumination/reflectorized name signs
	Unwarranted signals	Remove signals
	Inadequate signal timing	Upgrade signal system timing/phasing
Nighttime	Poor visibility or lighting	Install/improve street lighting Install/improve delineation/markings Install/improve warning signs
	Poor sign quality	Upgrade signing Provide illuminated/reflectorized signs
	Inadequate channelization or delineation	Install pavement markings Improve channelization/delineation

Exhibit 8.4-B GENERAL CRASH PATTERNS
(Continued)

GENERAL CRASH PATTERN		
Crash Pattern	**Probable Cause**	**Safety Enhancement**
Wet pavement	Slipper pavement	Improve skid resistance Groove existing pavement
	Inadequate drainage	Provide adequate drainage
	Inadequate pavement markings	Install raised/reflectorized pavement markings
Pedestrian/bicycle	Limited sight distance	Remove sight obstructions Install/improve pedestrian crossing signs and markings
	Inadequate protection	Add pedestrian refuge islands
	Inadequate signals/signs	Install/upgrade signals/signs
	Mid-block crossings	Install warning signs/markings
	Inadequate pavement markings	Supplement markings with signing Upgrade pavement markings
	Lack of crossing opportunity	Install traffic/pedestrian signals Install pedestrian crosswalk and signs
	Inadequate lighting	Improve lighting
	Excessive vehicle speed	Install proper warning signs
	Pedestrians/bicycles on roadway	Install sidewalks Install bike lanes/path Eliminate roadside obstructions Install curb ramps
	Long distance to nearest crosswalk	Install pedestrian crosswalk If warranted, install pedestrian actuated signals
Railroad crossings	Restricted sight distance	Remove sight obstructions Reduce grade Install active warning devices Install advance warning signs
	Poor visibility	Improve roadway lighting Increase size of signs Install advance markings to supplement signs
	Inadequate pavement markings	Install STOP bars Install/improve pavement markings
	Rough crossing surface	Improve crossing surface
	Sharp crossing angle	Rebuild crossing with proper angle or offset

Exhibit 8.4-B GENERAL CRASH PATTERNS
(Continued)

8.4.2.1 Potential Roadside Hazards Review

Conduct a site investigation of the roadway project. Document all potential roadside hazards that are outwardly visible, and include those documented in previous reports that still exist in the field. Exhibit 8.4-C presents an example of a roadside hazard review.

Document not only those elements that appear to be a potential hazard, but identify all of the site elements that point to past problems or items that required maintenance. Some examples include:

- locations of skid and tire marks, indicating where abrupt turns or stops were required;
- damaged guardrail sections;
- recently replaced signs, poles and barriers (indicating that something may have struck the previous feature);
- dips or bumps in the pavement;
- scars in the pavement (showing locations either rocks/debris have fallen, or where hitches/bumpers have scraped due to poor vertical alignment, grade or cross slope); and/or
- visible signs of impacts to the bottoms of bridges or overhead structures (showing a lack of vertical clearance for the vehicles using the roadway).

8.4.2.2 Two-Way Travel on Narrow, Single Lane Facilities

While not desirable, two-way travel on a narrow roadway cannot always be avoided, especially if widening the roadway would significantly interfere with the context of the adjacent landscape. When reviewing these facilities, document in particular where sight distance needs are critical issues. Rather than widening the entire roadway, perhaps only widening through the curves is necessary, especially if there is a low history of crashes on the facility.

8.4.2.3 Access Evaluation

Access Management seeks to improve traffic distribution, reduce vehicle conflicts and reduce crashes by providing better access control. Better access control can be achieved by combining, reducing and improving safety elements of access points. The result is a roadway that functions safely and efficiently for its useful life, and creates a more attractive corridor. A good access management plan can offer a great combination among operation, geometric design and safety.

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State: **Montana** Prepared by: **Paul Schneider**
County: **Flathead** Date: **May 19, 1996**

National Forest/Park: **Glacier National Park**

Highway Route: **US Route 2** Limits: **193+116 to 202+128** Length: **9.0 km**

General Location: **Beginning 1 km south of Camas and extending north to top of graveyard hill at Essex.**

Item	Hazard Location		Description of Hazard	Action	Cost	Remarks
	Station	Lt/Rt (m)				
1	193+438	6.0 Rt	100 x 100 wood sign post	Yes	$ 90	Relocate to backslope
2	194+082	4.9 Rt	100 x 100 wood sign post	Yes	$ 90	Relocate to backslope
3	194+243	5.5 Lt	Concrete culvert headwall	Yes	$ 500	Replace existing culvert
4	194+323	4.9 Rt	Concrete culvert headwall	Yes	$ 600	Replace existing culvert
5	194+564	3.7 Lt	Mailbox in no-passing zone	Widen	$1000	Provide mailbox turnout
6	194+886	4.3 Rt	Two 100 x 150 wood sign posts (not drilled)	Yes	$ 50	Drill posts
7	195+530	4.9 Lt	Abrupt culvert ends	Yes	$ 250	Lengthen culvert - metal end sections
8	196+013	4.6 Lt	Mailbox - good sight distance	No	-	Tight right-of-way
9	196+013	5.5 Lt	Abrupt approach road culvert	Yes	$ 600	Extend approach culvert and flatten slope to 1:10
10	196+174 to 196+656	6.7 Rt	Steep fill slope	None	-	Not cost effective guardrail
11	197+300	6.0 Lt	Concrete culvert headwall	Yes	$ 500	Replace and extend
12	198+105	5.5 Rt	Abrupt approach road culvert	Yes	$ 600	Extend culvert and flatten slope to 1:10
13	200+680	4.3 Rt	Concrete culvert headwall	Yes	$ 500	Replace existing culvert
14	201+645	3.7 Lt	Mailboxes (4)	Widen	$2500	Provide mailbox turnout

Exhibit 8.4-C SAMPLE ROADSIDE HAZARD REVIEW

8.4.2.4 Turning Movements, Intersection Sight Distance

Reserved

8.4.2.5 Adequate Facility Capacity

Queuing of traffic on the roadway that results from restricted access off of the main roadway, queuing at a toll/fee facility and/or vehicles stopping and accumulating at an overwhelmed intersection. Similar issues can occur with pedestrians as well. Reserved.

8.4.2.6 Appropriate, Visible Signing and Marking

Reserved for the following topics:

- *condition of signs/markings;*
- *visibility/location of signs/markings;*
- *reflectivity of signs/markings, if used at night;*
- *size of text/font on signs appropriate for posted speed; and*
- *light screening (at night due to facility lighting).*

8.4.2.7 Evaluation of Lighting and Traffic Signal Warrants

Reserved

8.4.3 EXISTING GEOMETRIC CONTROLLING FEATURES ANALYSIS

Refer to Chapter 4, Section 4.4 for determination of current design standards and controls that are applicable to the project.

Many existing highways do not meet current design standards and have safety deficiencies when compared to the current design standards of the AASHTO *Green Book*. The amount of upgrading necessary to bring an existing facility to current design standards has been a continuing concern. This concern was recognized in the 1982 *Surface Transportation Assistance Act*, Section 101(a), which emphasized safety by stating that RRR projects "shall be constructed in accordance with standards that preserve and extend the service life of the highways and enhance highway safety." Although the primary objective of RRR projects is to restore the structural integrity of the existing roadway both the safety and capacity of the facility should be reviewed and enhanced, when required.

To properly review an existing roadway for conformance to current and acceptable design criteria, the following factors should be evaluated. If the feature is within the current design guidelines, no changes are necessary. If the feature does not meet the current standards, it should either be improved or documented to warrant a design exception. Economics, anticipated growth, crash history, program schedules, time, manpower, etc., may have some bearing prior to final determination.

8.4.3.1 Horizontal/Vertical SSD

As-built plans are normally the best source of data available for evaluation of existing horizontal curves and vertical profile alignments. In some instances, hard copy maps or other survey information may be available in the absence of as-built plans. Once the existing alignment has been determined, the AASHTO *Green Book* can be utilized to determine the theoretical adequacy of the existing horizontal alignment and the vertical profile.

Stopping sight distance on horizontal curves is also an important feature that should be closely observed during the initial field review. During the drive through the project, features that would appear to restrict horizontal sight distance (e.g., narrow cut ditches, trees, outcroppings) should be observed. Measurements can be taken during the field visit to determine if restrictions do exist or additional data can be requested as needed.

8.4.3.2 Cross Section

Lane width and shoulder width on an existing roadway can be determined by researching the as-built plans or by actual field measurement. During the field reviews, lane and shoulder widths should be observed and verified as necessary to determine how the existing widths compare with AASHTO guidelines.

8.4.3.3 Existing Superelevation

While the degree of curvature shown on as-built plans is generally very reliable, the superelevation data cannot be relied upon because revisions to superelevation during construction may not have been well documented. Also, subsequent overlay projects and maintenance work may have changed the original superelevation.

Since as-built superelevation data may not be reliable, other means of reviewing superelevation are needed. It is not the intent to field survey each curve to determine actual values; however, the following actions should be performed during the initial field review:

- Observe the comfort level of the existing curves as they are driven through at the posted speeds.
- Arrange to discuss and review any particular problem areas with the maintenance foreman responsible for the area.

Maximum Superelevation rates vary, according to the climate and weather conditions. Refer to Chapter 4, Section 4.4.4.7 for guidance on maximum superelevation rates.

8.4.3.4 Roadway Cross Slope

AASHTO has established guidelines for ranges of cross slopes for various roadway classifications. The primary consideration on cross slope is to provide adequate pavement drainage. This item should be addressed by visual observation during the site visit. Also, agency maintenance representatives should be asked to provide any historical information in regard to problems with cross slope, ponding on the pavement or irregular shape of the cross section.

In some instances, the existing pavement cross section may have become distorted due to several overlays and/or maintenance treatment. If this is the case, the new pavement design should consider alternatives (e.g., additional removal, milling, total reconstruction) for the pavement section. This should be coordinated closely with the materials team and should be included as part of their pavement evaluation process.

8.4.3.5 Intersection Stopping Sight Distance/Decision Sight Distance

The at-grade intersections of the through facility with intersecting roads should be reviewed for adequacy of sight distance during the initial field review for the project. If there appears to be a potential problem with sight distance, the sight distance may need to be determined on site. Consideration should be given to modifications of obstructions occurring within the sight triangle. The location of the intersection on the vertical alignment is also an important factor.

8.4.3.6 Vertical Grades

The existing profile on a route can be determined by a review of the as-built plans. The review of the vertical alignment and stopping sight distance will provide some indication of grades that may need further evaluation. In general, AASHTO has established guidelines for suggested maximum grades for various roadway classifications.

8.4.3.7 Vertical Clearance

Underpass clearances at bridge structures should be verified through a review of the bridge inspection or maintenance reports. Existing clearances can then be compared with the AASHTO recommended clearances. Whenever a change in the existing profile grade on an existing route is being contemplated, the vertical clearances at existing structures should be reviewed to determine how the proposed changes in profile (e.g., overlay, mill) affect the clearance. AASHTO provides recommended vertical clearances for various roadway classifications.

8.4.3.8 Structural and Functional Sufficiency

Bridge width is defined as the minimum clear roadway width on the bridge as listed under the column heading “Curb to Curb” of the Bridge Record. For all existing bridges contained within the project limits, the bridge width should be compared with the AASHTO guidelines. AASHTO provides bridge width criteria for the various functional roadway classifications.

Structural sufficiency is determined in part by the maintaining agency, but is generally desirable to achieve a HS20 load rating, regardless of the functional classification of the roadway. AASHTO provides structural capacity criteria for the various roadway functional classifications. Refer to Chapter 10 for guidance on rating structural capacity.

Functional sufficiency is the adequacy of the bridge to carry the traffic volume and speed from an operational and capacity standpoint. Refer to the *Green Book* for guidance on the overall clear roadway width and design speed recommended for the particular functional classification and design traffic volume.

And finally, the bridge barrier type and sufficiency should be evaluated. For information regarding bridge barrier and off-bridge transition features (e.g., barrier curbs, walkways and roadside barriers) refer to the *Green Book*.

8.4.4 EVALUATION OF PEDESTRIAN/MULTI-MODAL FACILITIES

When evaluating the existing conditions, make a separate evaluation of the site from the perspective of pedestrians, bicyclists, handicapped persons and those using alternative forms of transportation (e.g., horseback, snowmobiles, ATVs). Clear delineation of the path these users are intended to follow, supplemented with adequate signing and information placards, is another important safety evaluation element of the roadway.

8.4.4.1 ADA Requirements

Refer to the *ADA Accessibility Guidelines for Buildings and Facilities* (ADAAG) for design guidelines.

8.4.4.2 Path Width/Accessibility

Where pedestrians are present, verify that the path for the pedestrian is clearly delineated. In addition, observe the paths that pedestrians choose to take and review the safety of the alternative routes. If any of these conditions are determined to be unsafe, positive pedestrian barriers such as railings may be necessary to ensure safe pedestrian crossings and keep them from crossing the roadway at hazardous locations.

The size of pedestrian facilities is volume dependent. The National Park Service uses many useful resources for estimating visitor traffic. These should be reviewed when sizing the sidewalk and pathway facilities.

8.4.4.3 Parking/Trails access from Roadways/Bridges

Pedestrians will generally use the shortest path of least resistance to reach their destination. If their destination is visible, and a "short-cut" can be seen that will significantly reduce their walking distance, given no other means of restriction, they may attempt to use the short-cut. Ingress/egress from trails, comfort stations, parking facilities and buildings must be coordinated with crosswalks and sidewalks.

If a sidewalk is not provided, the visitor may become resourceful and use other transportation facilities to view or access their desired destination. For example, if a bridge crosses a beautiful canyon and provides a unique photo opportunity, but does not have a sidewalk, most people will simply walk on the roadway. While some environmental and historic restrictions could prevent the structure from having a sidewalk, the designer must address how keep the pedestrian and vehicular traffic separated. This will likely require discussions with the resource agencies, but could reduce future safety implications if these concerns are addressed early in the design.

8.4.5 SAFETY EVALUATION COMPUTER PROGRAMS

Several computer programs are being developed to aide in the evaluation of the safety of an existing roadway. While these programs work as a great tool, they should not be used as a replacement of site evaluation and professional assessment.

8.4.5.1 Interactive Highway Safety Design Model (IHSDM)

IHSDM is a suite of software analysis tools for explicit, quantitative evaluation of safety and operational effects of geometric design decisions during the highway design process. It culminates a multiyear research and development effort conducted by the Federal Highway Administration.

IHSDM is intended for use throughout the highway design process from preliminary planning and engineering through detailed design to final review. It may be used both for projects to improve existing roadways and for projects to construct new roadways. The 2003 release of IHSDM has an initial focus on two-lane rural highways and has five evaluation modules:

- policy review,
- crash prediction,
- design consistency,
- intersection review, and
- traffic analysis.

Additional capabilities including a driver/vehicle module to provide measures of vehicle dynamics and evaluations of multilane rural highways are planned for future releases.

8.4.5.2 Roadside Safety Analysis Program (RSAP)

Highways are designed to provide motorists with reasonable levels of protection against serious run-off-the-road crashes. When hazards cannot be removed or relocated within the clear zone, a determination needs to be made if a safety device is warranted to protect motorists from the roadside obstacle. RSAP uses the concept of incremental benefit/cost analysis to weight the risk of death or injury to the motoring public against the initial cost of installing and maintaining the safety improvement. Appendix A of the *Roadside Design Guide* provides a cost-effective selection procedure for comparing alternative solutions to problem locations and instructions for operating the Roadside Safety Analysis Program (RSAP) computer software. The annual cost of each alternative is computed over a given period of time, taking into consideration initial costs, maintenance costs and crash costs. Crash costs incurred by the motorist, including vehicle damage and personal injury, are considered together with crash costs incurred by the highway department or agency. RSAP uses the concept of incremental benefit/cost analysis to weight the risk of death or injury to the motoring public against the initial cost of installing and maintaining the safety improvement. The alternative with the least total cost is normally selected, except when environmental or aesthetic considerations dictate otherwise.

The ability to easily vary input data allows the designer to explore various areas of sensitivity of the analysis at a given location. The effects of current traffic and future traffic can be explored to evaluate cost effectiveness over the design life of a project. Although most of the data collected through research pertains to high-speed situations, the designer can analyze how sensitive the cost effectiveness is with respect to the severity index. However, a correlation can be made provided the designer recognizes that lower design/running speeds would lessen severity. Use of this tool has been successful in persuading reluctant agencies to recognize the cost effectiveness of selected safety feature applications.

This program accesses research information by Kennedy-Hutcheson for high-volume roads and Glennon for low-volume roads with roadway widths less than 8.5 m (28.0 ft). The program shows both annual cost comparison and present worth. Generally, the annual cost is used to facilitate comparison of different alternatives with varying design life.

Refer to NCHRP Report 492[a5].

8.4.5.3 Resurfacing Safety Resource Allocation Program (RSRAP)

Highway agencies face a dilemma in determining the appropriate balance of resurfacing and safety improvement in their programs to maintain the structural integrity and ride quality of highway pavement. RSRAP uses an optimization process based on integer programming to determine which improvement alternatives (or combinations of alternatives) would optimize system wide safety benefits for a given set of resurfacing projects.

8.4.6 ROAD SAFETY AUDITS

A road safety audit (RSA) is a formal safety performance examination of an existing or future road or intersection by an independent audit team. They can be performed during any stage of project development from planning through construction and throughout the operation of the completed facility. RSAs can also be used on any size project, from minor maintenance assessments to major new program expansions. Typical improvements suggested include:

- removal of sight distance obstructions,
- addition/design changes to turn lanes,
- improvement to acceleration/deceleration lane design,
- illumination,
- median barrier placement,
- consideration of pedestrian's ability to cross a street,
- improvements to superelevation,
- drainage improvements,
- roadway shoulder and lane width modifications,
- access management/consideration of driveways,
- realignment of intersection approaches, and
- improvements to signing and pavement marking.

The recommended procedure for conducting an RSA is as follows:

1. **Audit Team**. Following identification of a project or roadway that is to be evaluated, select an interdisciplinary audit team to review the installation. The team should consist of three to five people from various design and maintenance disciplines including highway design, traffic safety, traffic engineering, planning, geometric design, construction, maintenance, human factors and enforcement.

2. **Pre-Audit Meeting**. Conduct a pre-audit meeting with the interdisciplinary team and the Project Owner/Design Team to review available project drawings and site information.

3. **Field Review**. Consider field reviews under various conditions. The team should have the willingness to investigate new ideas outside the traditional scope of work.

4. **Audit Analysis**. Conduct audit analysis and prepare a report listing the team's findings.

5. **Report Audit Findings**. Present report and audit findings to the Project Owner/Design Team.

6. **Prepare Formal Response**. The Project Owner/Design Team prepares a formal response, incorporating the findings into the project when appropriate.

RSAs are different from traditional safety reviews because these multi-discipline team reviews tend to be more proactive, considering all of the various types of road users that may be using the facility and all of the factors that contribute to a crash. These reviews include day and night field reviews by independent teams. The energy created by these teams has resulted in more safety implementation recommendations being recommended than in the past when only one safety individual was responsible for the review.

8.4.7 SAFETY EVALUATION REPORT

After the accumulation of available data, this information and all observations must be consolidated and documented in a Safety Evaluation Report. The results of the crash analysis and the list of potential roadside hazards provide the input for this evaluation. From these two sources, the designer should develop a composite list that locates and describes the identified safety problems.

Alternatives for correcting the safety problems should be developed and evaluated for effectiveness, cost and environmental impact. Alternatives may range from site-specific improvements to total reconstruction. The evaluations, alternatives and the action selected should be documented in the project files.

8.5 SAFETY DESIGN

8.5.1 DESIGN EXCEPTIONS

Although often viewed as dictating a set of national standards, the AASHTO *Green Book* is actually a series of guidelines on geometric design within which the designer has a range of flexibility. As stated in the forward to this document:

> *"The intent of this policy is to provide guidance to the designer by referencing a recommended range of values for critical dimensions. Sufficient flexibility is permitted to encourage independent designs tailored to particular situations."*

While it provides guidance on the geometric dimensions of the roadway (e.g., travel lanes, medians, shoulders, clear zones), there are many aspects of design that are not directly addressed in the *Green Book*. Despite the range of flexibility that exists with respect to virtually all the major road design features, there are situations in which the application of even the minimum criteria would result in unacceptably high costs or major impact on the adjacent environment. For these instances, the design exception process allows for the use of criteria lower than those specified as minimum acceptable values in the *Green Book*.

For a full discussion on the elements that must be addressed in a design exception, refer to Chapter 9, Section 9.1.3.

8.5.2 DEFINING THE CLEAR ZONE

A clear zone (L_c) is defined as the roadside border area (starting at the edge of the traveled way) that is available for safe use by errant vehicles. The width of the clear zone is influenced by the type and volume of traffic, speed, horizontal alignment and side slopes. Slopes steeper than 1V:3H are not considered traversable by vehicles and slopes steeper than 1V:4H are considered non-recoverable. The need for traffic barriers as discussed in Section 8.5.5 should be evaluated when slopes within the clear zone are in these ranges.

Determine clear zone widths for all roadway sections by using Table 3.1 or Figure 3.1 of the AASHTO *Roadside Design Guide*. Where feasible and environmentally acceptable, the clear zone width should be a minimum of 3 m (10 ft). On rural collectors and local roads and streets with a design speed of less than 60 km/h (40 mph) or an ADT less than 750, the clear zone width may be determined and documented on a project-by-project basis.

8.5.3 TRAFFIC BARRIERS

When clear zone requirements cannot be met, the designer should give special attention to the roadside hazards. Obstacles located within the clear zone should be removed, redesigned, relocated or made breakaway. If this is not feasible, then guardrail or some other type of roadside barrier should be considered, provided that the roadside barrier offers the least hazard potential. If it is determined that a traffic barrier is not needed, consider delineating the hazard.

While the following Sections provide policy and direction for installing traffic barriers, the designer should also review the FLH Barrier Guide [scheduled for release in January 2006] for a more comprehensive review of available barriers, their applications and their installation requirements.

8.5.3.1 Identifying Needs

Roadside obstacles may be classified as non-traversable hazards or fixed objects.

The following are examples of non-traversable hazards that may warrant roadside barriers:

- steep embankments (slopes steeper than 1V:3H),
- rock cuts,
- large boulders,
- ditches,
- culvert openings,
- permanent bodies of water over 0.6 m (2.0 ft) in depth,
- large trees over 100 mm (4 in) diameter, and/or
- shoulder edge drop-offs steeper than 1V:1H and depth greater than 0.6 m (2.0 ft).

A ditch section is safe or hazardous depending upon the type of sideslopes and widths. The *Roadside Design Guide* contains examples for a variety of ditch configurations. Frequently, limited right-of-way, environmental factors and terrain will preclude the designer from being able to develop these preferred ditch sections. Preferred ditch sections should receive greater consideration on high-speed, high-volume facilities. Medians on divided roadways also deserve special attention.

The following are examples of fixed objects that may warrant roadside barriers:

- bridge piers, abutments, parapets or railings;
- retaining walls;
- the fixed sign bridge and non-breakaway sign supports;
- trees over 100 mm (4 in) in diameter;
- headwalls of box culverts or pipe culverts;
- culvert end sections with diameters larger than 900 mm (36 in); and/or
- utility appurtenances.

The unprotected end of a bridge rail or parapet is considered a hazard. In most designs, an approach roadside barrier with a smooth transition to the bridge barrier is warranted. Exceptions to this policy may include structures designed for use on low-volume, low-speed highways. The *Roadside Design Guide* contains discussions for transition barriers.

Special attention should be given to the proper attachment of the transition railing with the bridge railing or parapet. The railing connection should develop the full tensile strength of the rail element and be designed to prevent possible pocketing or snagging of a vehicle on the end of the bridge parapet. The bridge plans should generally include special drawings of these connection details. Transition guardrail should satisfy the minimum length of need to develop its full tensile strength capacity. The terminal end should extend outside the lateral clear zone or be provided with a crash worthy terminal, protected by a crash cushion or buried in a cut slope.

On many projects, existing bridges have inadequate bridge or transition railings. When replacing structurally obsolete bridges, railing replacement should meet current standards. When bridge railings are structurally adequate but functionally obsolete, engineering analysis should be performed to determine the recommended action on a case-by-case basis.

Crashes involving roadside hazards represent a problem inherent to any existing highway facility. Even on new or reconstructed projects, the complete elimination of all roadside hazards may not be feasible or practical. See Section 8.1.4 for a priority list when evaluating roadside hazards.

When determining the need for traffic barriers, consider cost when evaluating the following four alternatives:

1. **Remove or Reduce Hazard. This option should only be considered if it is determined that shielding is unnecessary.**

2. **Install a Barrier**. With regard to installing a barrier, RSAP (Section 8.4.5.2) allows the designer to evaluate any number of barriers that can be used to shield the hazard. Through this method, the following can be evaluated:

   - the effects of average daily traffic,
   - offset of barrier or hazard,
   - size of barrier or hazard, and
   - the relative severity of the barrier or the hazard.

   For low-volume, low-speed roads, strict adherence to the guardrail warrants are shown in the Roadside Design Guide is frequently not practical or cost-effective.

   NPS and FHWA have jointly developed *Park Road Standards*, published by NPS in 1984.

   The *Park Road Standards* state:

   > *"Guardrail or guardwalls should be installed at points of unusual danger such as sharp curves and steep embankments, particularly at those points that are unusual compared with the overall characteristics of the road."*

   Similar wording is used in the AASHTO *Green Book* in the section that deals with recreational roads.

Although the *Roadside Design Guide* is still used as a basis for determining need for barriers on recreational roads, they are not always appropriate to these roads. Besides low speeds and low volumes, NPS roads frequently have other characteristics that affect barrier needs. These include the following:

- roads closed in winter and during periods of hazardous climatic conditions,
- roads closed at dark, and
- roads with access limited to passenger-carrying vehicles.

Another consideration affecting the use of barriers is for areas that have unusual environmental sensitivity (e.g., endangered plants and animals, major historic and scenic resources).

The "unusual danger" noted in the *Park Road Standards*, when compared with the rest of the roadway, has been reduced to the following criteria for roads that have continuous sharp curves and steep slopes throughout much of their lengths:

- Consider barriers in areas with high embankments and slopes steeper than 1V:2H and where rock embankments and retaining walls prevent the growth of vegetation.

- Consider barriers in areas with steep slopes or other roadside hazards where unusual conditions exist that may surprise or distract the motorist. For example, sharp curves at the end of long tangents (especially on downgrades) or approaches to scenic vistas at sharp curves.

- Consider barriers at locations with crash histories where the severity could have been reduced with a barrier.

Always remember that a barrier is itself a significant hazard and is more likely to be hit than the hazard it is intended to protect. Therefore, the relative severity, costs and frequency of crashes must be considered.

Although the warrants cover a wide range of roadside conditions, special cases or conditions will arise for which there is no clear choice. These cases must be evaluated on an individual basis, and, in the final analysis, must usually be solved by engineering judgment.

3. **Sign or Delineate Hazard**. Signing or delineating a hazard is typically cost-effective on low-volume and/or low-speed facilities, or where the probability of crashes is low.

4. **Do Nothing**. Use this option only after determining that other alternatives are not cost-effective in reducing the risk of crashes.

8.5.3.2 Type Selection

Once it has been determined that a barrier is needed, type selection will be made. While the most predominant type of roadside barrier used on Federal Lands' projects is metal W-beam guardrail, the designer needs to be cognizant of various selection criteria for roadside barriers. Exhibit 8.5-A lists the various criteria that should be considered.

The designer is again referred to the *Roadside Design Guide* and the Approved Hardware website for design criteria of the various systems.

The FLH has conducted crash tests using the National Cooperative Highway Research Reports (NCHRP) 230 and 350 criteria to evaluate aesthetic barrier systems. Acceptable crash test results and their respective designs are available online at FHWA's website. Research efforts are in progress to identify and crash-test other systems for possible use on FLH Program projects.

The owner agency generally selects the type of roadside barrier. It is the designer's responsibility to ensure that the selected barrier has been tested and approved for use and designed to function where installed.

The FHWA Final Rule, published in the *Federal Register* on July 16, 1993, required that roadside safety hardware installed on the National Highway System (NHS) routes must meet the requirements of NCHRP 350. The FLH policy requiring barrier systems to meet the requirements of NCHRP 350 is provided below:

1. **Routes on the NHS**. The following applies:

    a. *State and local routes*. **As required by FHWA, it is the policy of the FLH to use only roadside safety hardware that meets NCHRP 350 criteria. No exceptions are permitted, except for specific hardware items receiving delays or temporary waivers granted by the FHWA, Office of Safety Design (HSA-10).**

    b. *National Park Service (NPS) routes.* **It is also the policy of the FLH that all roadside safety hardware shall meet NCHRP 350 criteria on NPS routes.**

    A request for acceptance of aesthetic barrier systems previously accepted under NCHRP 230 may be submitted to the Office of Safety Design for consideration. The Office of Safety Design may determine that the barrier is acceptable under NCHRP 350 criteria without retesting if the test result data under NCHRP 230, or results from similar systems tested under NCHRP 350, indicate the system is likely to meet NCHRP 350 criteria.

Characteristic	Considerations
Deflection	Space available behind barrier must be adequate to permit dynamic deflection of barriers.
Strength and Safety	System should contain and redirect vehicle at design conditions. System should be as safe as possible considering costs and other considerations.
Maintenance	Collision maintenance. Routine maintenance. Environmental conditions. Inventory of spare parts.
Compatibility	Can system be transitioned to other barriers? Can system be terminated properly?
Costs	Initial costs. Maintenance costs. Crash cost to motorist.
Field Experience	Documented evidence of barrier's performance in the field.
Aesthetics	Barrier should have a pleasing appearance.
Promising New Designs	It may be desirable to install new systems on an experimental basis.

Exhibit 8.5-A SELECTION CRITERIA FOR ROADSIDE BARRIERS

2. **Routes not on the NHS**. The FLH shall comply with the owning agency's policies on roadside safety hardware on non-NHS routes. The owning agency's policies will be referenced as the reasons for permitting barrier systems that do not meet NCHRP 350 criteria. However, no barrier systems shall be used that have not passed NCHRP 230 criteria. If the agency has no policy, FLH shall specify roadside safety hardware that meets NCHRP 350 criteria. Although there is no regulatory requirement, the FHWA strongly encourages safety hardware used on non-NHS routes to meet NCHRP 350 criteria.

   State and local routes. Due to particular issues (e.g., maintenance of barrier systems), State or local agencies may require barrier systems that do not meet

NCHRP 350 criteria. **The FLH Divisions shall ensure the owning agencies are aware that proposed systems do not meet NCHRP 350 criteria before complying with the owning agencies' requests. The FLH Divisions should document reasons for specifying barrier systems that do not meet NCHRP 350 criteria.**

b. *NPS routes*. All barrier systems shall meet NCHRP 350 criteria. The decision to use barrier systems that do not meet NCHRP 350 criteria should be documented.

Roadside safety hardware meeting NCHRP 350 criteria are currently being accepted by the Office of Safety Design following a review of data submitted by the vendor or the developer of the system. Updated lists of approved barrier systems may be found on the FHWA website. If no acceptable non-proprietary barrier terminal systems and transitions are available that meet the project needs, at least three acceptable proprietary systems (if available) shall be permitted as options in the contract.

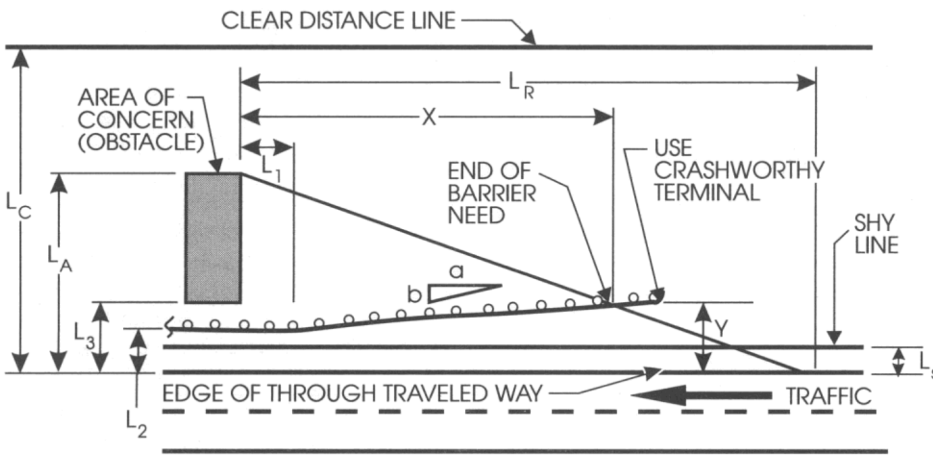
8.5.3.3 Design Procedures

Once the need for barrier has been determined, the designer must determine the length and location for the barrier. The following discussion outlines the significant elements for locating and designing roadside barriers. However, the designer must refer to the *Roadside Design Guide* for specific details and limiting criteria for layout and use of the barrier selected.

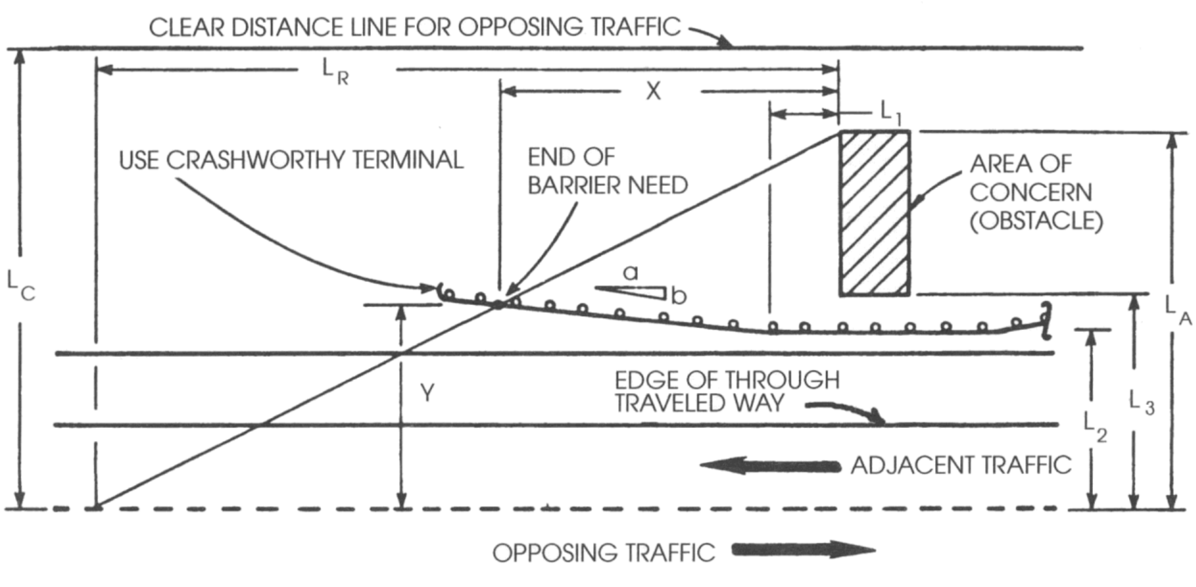
8.5.3.3.1 Length of Barrier

The length of need is equal to the length of the area of concern parallel to the roadway, plus the length of the approach barrier on the upstream side (and downstream side, if needed), plus a safety end treatment.

Where slopes outside of the graded shoulder are flat enough, the barrier approach should be flared or the guardrail installation should be located outside of the graded shoulder to minimize the length of need. More commonly, where slopes are steeper, the barrier will run along the shoulder. Exhibit 8.5-B depicts both cases. The minimum barrier lengths in advance of the hazardous area shown are adequate for most installations.



Approach Barrier Layout for Adjacent Traffic



Approach Barrier Layout for Opposing Traffic

Exhibit 8.5-B GUARDRAIL LENGTH REQUIREMENTS

8.5.3.3.2 Location of Barrier

The location of a barrier may be one of the following:

1. **Adjacent to the Graded Shoulder**. Designers should be aware that barrier installations require widening of the shoulder to provide adequate soil support. In addition, special attention is required at barrier terminals to ensure that widened areas are graded correctly so that the terminal will function properly.

2. **Back of the Graded Shoulder**. Where barriers are located in back of the graded shoulder or when barriers are flared back of the shoulder edge, slopes in front of the barrier shall be 1V:10H or flatter. Also, the algebraic difference between the shoulder slope and the slope in front of the guardrail should not be greater than 8 percent.

3. **Adjacent to a Retaining Wall Face**. When barriers are located near the edge of a retaining wall, there may not be adequate support behind the barrier for the embedded posts to properly sustain the impact loading and may require project-specific design. For example, the supports may need to be founded in a cantilever-spread footing and require a special structural design. For these situations, both the structural and highway safety engineers need to review the proposed installation.

8.5.3.3.3 Barrier/Curb Combinations

The following briefly describes barrier/curb combinations:

1. **All Barrier/Curb Combinations**. Concrete curb and gutter, header curb or other rigid-type curb used in combination with a barrier should be avoided whenever possible. Curbs should not be used in front of barriers unless the combination has been successfully crash-tested.

2. **Guardrail/Curb Combinations**. Where there are no other feasible alternatives to guardrail/curb combinations, the face-of-curb should be located behind or flush with the face of guardrail. However, crash tests have shown some guardrail/curb combinations with curbs located flush with the face of the guardrail can cause vaulting due to deflection of the rail. Therefore, curbs higher than 100 mm (4 in) should not be used with guardrail unless:

   - the guardrail/curb combination has been successfully crash-tested, or
   - the rail is adequately reinforced (stiffened) to reduce its deflection.

   On low-speed roads, use of a reinforced rail may not be cost-effective. These locations are best analyzed on a case-by-case basis, taking actual or anticipated operating speeds into account and considering the consequences of vehicular penetration.

The *Roadside Design Guide* contains additional information on curb and barrier/curb combinations.

8.5.3.3.4 Shy Distance

Barriers are themselves items that must be avoided. Placed at the edge of the roadway, most drivers will provide an extra cushion of separation from the barrier to ensure that neither their vehicle nor the barrier is damaged. This separation is called the shy distance and it varies with respect to speed and the size of the obstacle. It is defined as the distance from the edge of the traveled way beyond which the typical driver will not perceive a roadside object as an immediate obstacle. Placed any closer to the edge of the roadway, the driver may feel compelled to either change the vehicle’s placement or reduce its speed.

As a rule of thumb, barrier should be placed an additional 0.6 m (2 ft) beyond the edge of the prevailing shoulder to retain the driver’s perception of a constant width roadway. A more detailed discussion is available in the AASHTO *Roadside Design Guide*, Section 5.6, which provides additional information on what the suggested shy distance should be, based on various design speeds and obstacle offsets.

8.5.3.3.5 Transitions

Bridge rail transitions may require a short section of concrete barrier wall to provide an attachment point between the bridge railing and the approach roadway barrier transition terminal. One example of this transition is the thrie-to-W-beam transition which is used on many bridge rail retrofit jobs. Currently, there is no standard drawing/detail for these installations; however they are very common throughout FLH with details available from suppliers and many DOT sites.

Future Discussion Topic: What to do when there are constraints at the ends and a post with block cannot be used or approach railing needs to be curved.

8.5.3.4 Bridge Railings

Selection of the appropriate barrier, both on a bridge structure and approaching the bridge structure, requires cooperation between the bridge and roadway disciplines. In addition, attention to aesthetics, maintenance and its ability to deflect an errant vehicle must all be evaluated before the type of bridge railing is selected.

Future Discussion Topic: In addition to providing support for the selection of an appropriate bridge rail, the following discussion points will be discussed further:

- *details around the approach slab,*
- *foundations/anchors approaching bridges,*
- *how/where to transition, and*
- *NCHRP Report 350 Compliance for Crash-Tested Railings.*

8.5.4 CRASH CUSHIONS AND END TREATMENTS

Crash cushions shield errant vehicles from impacting fixed rigid hazards (e.g., an intersection of bridge parapets at a gore area) by smoothly decelerating the vehicle to a stop condition when hit head on. Also, it is desirable for the crash cushion to redirect a vehicle when hit from the side by functioning in a manner similar to a longitudinal barrier.

End Treatments are devices that are designed to treat the end of a longitudinal barrier. The end treatment may function by:

- decelerating a vehicle to a safe stop in a relatively short distance,
- permitting controlled penetration of the vehicle behind the device,
- containing and redirecting the vehicle, or
- a combination of any of the above.

These devices may be located in roadway medians, gore areas or along the roadside. These devices have been developed for specific applications (e.g., limited shoulder width, temporary construction installations, high frequency impact sites, the protection of wide hazards, and the protection of fixed features that protrude into the clear zone).

8.5.4.1 Determination of Need

As with longitudinal barriers, the first consideration with regard to a rigid object or a hazardous condition is to evaluate the feasibility of removing the obstruction, relocating it or making it breakaway. When these options are not feasible, the next step is to determine whether or not analyzing the cost effectiveness warrants some type of barrier as described in Section 8.5.4.2. The cost-effective procedure can be used to evaluate both longitudinal barriers as well as crash cushions. Before the development of crash cushions, many fixed object hazards could not be effectively shielded at all; therefore, where appropriate, crash cushions may prove to be very helpful.

8.5.4.2 Types of Treatments

The *Roadside Design Guide* presents several approved crash cushions and end treatments. Updated lists of approved crash cushions may be found on the FHWA website. Crash test criteria can be found in NCHRP Report 350.

8.5.4.3 Design Procedures

While the use of crash cushions on FLH projects is expected to be quite limited, the designer should realize that rapid development in this area is occurring. Where use of a crash cushion is warranted, the designer should ensure that the most recent design criteria are used.

8.5.5 TEMPORARY TRAFFIC CONTROL (TTC)

The safe and efficient movement of traffic through the highway project necessitates that designers review the proposed design from a traffic operations standpoint. The designer needs to be alert for situations that involve alterations in the driver's behavior or changes in driver attention. During the design phase, the designer should attempt to perceive the final roadway as it will appear to the motorist anticipating the necessary traffic control devices. Traffic control devices are intended to provide the user with sufficient advance information so the highway can be driven safely. Through the proper application of design standards, the number of motorist decision points will be minimized. There will, however, always be a need for appropriate permanent traffic control devices to inform, regulate and/or warn the motorist. A review of the safety analysis will generally identify areas of existing operational problems.

Field reviews during construction are encouraged to substantiate if the original perceived operational characteristics of the project were germane and to provide timely adjustments during construction should they be warranted. After construction is completed and the project is opened to traffic, an evaluation should be made of the traffic control devices to determine their adequacy and if they are functioning as planned.

8.5.5.1 TTC through the Construction Site

Construction activity presents many traffic control problems that must be addressed by the designer. Regardless of whether the project is open or closed to public traffic, some form of construction traffic control will be required. A plan directed to the safe and expeditious movement of traffic through construction and to the safety of the work force performing those operations is defined as a TTC Plan.

It is FLH policy that a TTC plan be designed and incorporated into all projects.

8.5.5.2 TTC Plan Development

The purpose of the TTC plan is to anticipate and describe those traffic control measures that will be necessary during project construction and to outline coordination needs with owner agencies and the public.

TTC plans will vary in scope and complexity depending upon the type and volume of traffic and the nature of the construction project. At an early stage in the project development, the development of the TTC plan should begin and a determination made of the nature and volume of current and predicted traffic. All interested agencies should be involved throughout the development of the TTC plan. For projects with low-traffic volumes or that otherwise have few traffic hazards or conflicts, the TTC plan may be quite simple.

For projects that have one or more of the following characteristics, the TTC plan will normally be more complex:

- high-volume or high-speed traffic;
- rush hour or seasonal traffic patterns;
- heavy use by bicycles, pedestrians or disabled persons;
- changing work conditions or other conditions that would be confusing to the traveling public;
- hazards due to nighttime operations;
- detours or complex traffic patterns; and/or
- closely spaced intersections, interchanges or other decision points.

In developing the TTC plan, consider the items in Exhibit 8.5-C as appropriate. These items may be used as a checklist in either developing or reviewing the adequacy of traffic control plans.

All TTC plan features, which are obligations on the part of the contractor, shall be included in the plans and specifications. When necessary, appropriate project-specific or standard typical traffic schemes shall be included in the plans.

The *MUTCD* must be used as a standard for signs, striping and other traffic control devices. Because of the general nature of the *MUTCD*, it will usually be necessary to use supplemental information.

The contract PS&E must include the minimum requirements for controlling traffic through the construction work zones. However, the contractor may furnish alternate or additional means for accommodating traffic, subject to approval of the engineer.

Include traffic control provisions in the PS&E distribution made to other offices and agencies for review before advertising in order that these other parties may have an opportunity to review the provisions for adequacy and coordination.

Payment for TTC plan activities will usually be made by individual bid items for services, traffic control devices, signing, etc. For projects with only light traffic where traffic control procedures are minimal, payment may be incidental to other items of work, or paid for on a lump-sum basis.

There may be certain traffic control information that is of value to the project engineer but should not be included in the contract. In this case, this type of information should be documented and copies provided to the appropriate Construction Units. This information may include the following:

To Be Provided

Exhibit 8.5-C TRAFFIC CONTROL PLAN

- the need for public relations (e.g., notifications to the local news media);
- any special agreements reached with other agencies relating to traffic control or traffic management;
- crash reporting requirements; and
- any special guidance on traffic management for the project engineer.

The TTC plan as contained in the contract must be adopted by the contractor unless an alternate TTC plan is developed by the contractor and approved by the engineer prior to beginning construction operations.

8.5.5.3 TTC Pavement Markings

The TTC plan should reflect FLH policy that pavement markings conforming to full *MUTCD* standards shall be installed as quickly as practical in the construction process. Special standards described below are available to accommodate the periods of time before installation of permanent markings is practical.

8.5.5.3.1 Definitions

1. **Temporary Pavement Markings**. Either interim or standard markings installed prior to the installation of permanent markings.

2. **Interim Markings**. Interim markings are special, reduced dimension, temporary centerline and lane line markings, which are permitted by *MUTCD* Section 6F.72 or raised pavement markers permitted by Section 6F.73. Interim markings are permitted on new pavement lifts when additional pavement lifts or standard markings are to be installed within two weeks. Interim markings must conform to the color and retroreflective requirements of the *MUTCD*.

3. **Standard Markings**. Standard markings are centerline, lane line, and no-passing zone markings that comply fully with the dimensional, color and retroreflective requirements of the *MUTCD*. Standard markings may be either temporary or permanent, although permanent markings typically have additional contractual requirements.

4. **Vehicle Positioning Guides**. Temporary raised pavement markers, installed on centerline and lane lines immediately after paving but prior to the installation of temporary or permanent pavement markings.

5. **Severe Curvature**. Roads with a design speed of 55 km/h (35 mph) or less, or curves with design speeds of at least 15 km/h (10 mph) less than the design speed for the remainder of the road.

8.5.5.3.2 Unmarked Pavement

Section 6F.72 of the *MUTCD* permits a limited period of unmarked pavement upon opening to traffic and prior to the required installation of temporary or permanent markings. The traffic volume as outlined in Sections 8.5.5.3.4 and 8.5.5.3.5 defines the time limitations. During this period, it is recommended that adequate delineation and signing be provided as follows:

- Vehicle positioning guides shall be installed on centerline and lane lines at a maximum spacing of N (N = cycle length, usually 12 m (40 ft)) in combination with appropriate signs, channelizing devices and other delineation. Spacing should be reduced to 0.5 N in severe curvature situations.

- A warning sign, “UNMARKED PAVEMENT,” shall be placed at the beginning of each unmarked section, and after each major intersection or entrance ramp.

- If sections of severe curvature or restricted visibility dominate the construction area, such that passing zones are inappropriate throughout the project, standard advance warning signing at the beginning of the project shall include “NO PASSING NEXT XX Miles” rounded to the nearest whole meter (mile). In addition, an R 4-1 “DO NOT PASS” sign shall be installed at the beginning of the project and approximately every 1.6 km (1 mi) thereafter.

- If each no-passing zone is to be signed separately, an R 4-1 “DO NOT PASS” sign shall be used at the beginning of each zone, and repeated at maximum 1.6 km (1 mi) intervals, if necessary. At the end of each zone, an R 4-2 “PASS WITH CARE” sign shall be used. On other than low-volume roads, and when special hazards are present, the R 4-1 sign at the beginning of each zone should be supplemented by a W 14-3 “NO PASSING ZONE” sign.

8.5.5.3.3 Marked Pavement

Temporary markings are required if the time limitations as described for unmarked pavement are exceeded and it remains impractical to install permanent markings. Temporary markings should be standard markings, unless the specific time limitations of temporary markings can be met. The following are special standards for temporary markings:

1. **Centerlines and Lane Lines**. *MUTCD* Section 6F.72 requires interim broken-line pavement markings to be 0.6-m (2-ft) stripes on 12-m (40-ft) cycles or 0.6-m (2-ft) stripes on 6-m (20-ft) cycles in severe curves. When 30 percent or more of the road is designated as meeting the criterion for severe curvature, the entire road may be striped on a 6-m (20-ft) cycle. Temporary raised pavement markers may be substituted for broken line segments, and solid lines, in accordance with spacing described in the *FP*.

2. **Edge Lines**. Temporary edge lines are not required, except that if there is a winter shutdown or extended delay of six weeks or more in the completion of paving and installation of permanent markings. Temporary edge lines meeting the requirements of

the *MUTCD* must be installed on those roads where edge lines were present prior to construction and permanent edge lines are specified in the contract.

8.5.5.3.4 Time Limitations — Roads with the ADT < 1000

Where average daily traffic does not exceed 1000 veh/day, and where the installation of permanent markings is not practical or possible immediately prior to opening the road to traffic, the following applies:

- For a scheduled duration of not more than two weeks after opening of a new lift of pavement, the minimum requirements of Section 8.5.5.3.2 apply.
- As an option to unmarked pavement during the same two-week time frame, temporary centerline markings meeting the standards of interim markings as defined in Section 8.5.5.3.3 are permitted.
- For a scheduled duration of more than two weeks after the opening of a new lift of pavement, the minimum requirements of standard markings as defined in Section 8.5.5.3.1 apply; as well as the requirements for edge lines in Section 8.5.5.3.3.

8.5.5.3.5 Time Limitations — Roads with the ADT > 1000

Where the average daily traffic exceeds 1000 veh/day, and where the installation of permanent pavement markings is not practical immediately prior to opening the road to traffic, the following applies:

- For a scheduled duration of not more than three days after the opening of a new lift of pavement, the minimum requirements of Section 8.5.5.3.2 apply.
- For a scheduled duration of not more than two weeks after opening a new lift of pavement, the minimum requirements of interim markings as defined in Section 8.5.5.3.1.
- For scheduled duration of more than two weeks after opening a new lift of pavement, the minimum requirements of standard markings as defined in Section 8.5.5.3.1 as well as the requirements for edge lines in Section 8.5.5.3.3 apply.

8.5.5.3.6 Contract Items

Contract requirements and contract items should be structured to assure safety while not subsidizing or encouraging delays, inefficiencies and excessive use of temporary markings and related traffic control.

Vehicle positioning guides are not considered centerline markings. They may be paid for as vehicle positioning guides or considered a subsidiary obligation. Additional signing and/or channelization devices necessary during periods of unmarked pavement should be anticipated and included in the TTC plan.

Because the *Standard Specifications* (see Section 9.6.10) prohibit painted temporary markings on the final lift of pavement, it may be appropriate to include a contract item for temporary markings for lifts other than the final lift, but not for the final lift. This will minimize the cost of the temporary markings item and encourage the contractor to schedule permanent markings on the final lift in a timely manner.

8.5.5.3.7 No Existing Markings

Where the existing road, prior to construction, has no markings, then temporary markings are not required prior to completion of the work. However, if the construction is nearly complete, including one or more lifts of pavement materials, and has upgraded the geometrics and increased prevailing speeds, temporary markings are required in accordance with Section 8.5.5.3.3.

8.5.5.3.8 One-Lane Paving

Where only one lane of a two-lane road is being paved during construction and the second lane is paved the following day (permitted by the *FP* depending on lift thicknesses), the paving must be offset so that the existing markings are not obscured or temporary markings must be installed on the one lane mat prior to opening it to traffic. In addition, an UNEVEN LANES sign (W8-11) should be used in this situation.

8.5.5.3.9 Special Pavement Markings

The need for temporary school zone, railroad, cross walk, stop line and other special pavement markings must be evaluated on a case-by-case basis during the design process. Markings that are deemed warranted must be included in the contract. Bicycle and pedestrian traffic, limited sight distance and other potential hazards should also be considered during the design process as well as traffic volume and the duration of construction.

8.5.5.3.10 Diversions and Detours

Paved temporary roads and detours that carry other than low-volume traffic, or are to be used in excess of two weeks must receive the standard markings in accordance with the *MUTCD*. When two-way traffic is detoured onto what would ordinarily be a one-way road, or what may appear to be a one-way road, signing must be supplemented with (W6-3) TWO-WAY TRAFFIC signs at maximum intervals of 1.6 km (1 mi).

8.5.5.3.11 State Standards

Designers should be cognizant of prevailing State standards and make adjustments (i.e., more stringent standards) to FLH requirements, wherever appropriate.

8.5.5.3.12 Contract Provisions

It is important to structure contracts so that major overruns and unnecessary government liability for short-term markings will not occur if the contractor elects to perform the paving and marking differently than the designer assumed. The following are general guidelines that must be reevaluated on a case-by-case basis:

- There should be sufficient quantities of temporary markings to accommodate each lift of paving materials anticipated during construction.

- The contractor should be given the option of furnishing painted markings, reflective tape or temporary raised pavement markers. The bid item should include removal when required. Generally, painted short-term markings are cheapest and are appropriate immediately behind the paving operation on intermediate lifts. The temporary raised pavement markers are more practical on final lifts since they are easily removable prior to installing permanent markings, and are usually less expensive than reflective tape on roads with extensive no-passing zones. Where aesthetics are important, it may be appropriate to prohibit temporary painted markings on the final lift.

- The Government is not obligated to pay for two systems on the same lift. If the time limit for short-term interim markings expires due to poor scheduling, and the contractor has to install short-term standard markings, then the upgrade should be at the contractor’s expense.

- For large projects, it is intended that the time limitations on short-term interim markings will force the contractor to complete manageable sections of the project through permanent striping, rather than have the entire project partially complete for an unacceptably long period of time.

8.5.5.4 TTC Channelizing Devices

The preferred channelizing device for any application involving both day and night usage is the drum. If clearance or width problems preclude the use of drums, other devices (e.g., vertical panels, barricades, tubular markers) may be substituted. All devices must meet current crashworthiness standards.

The TTC plan should address and contain appropriate standards defining the expected condition of the traveled way and the needs of the public through the duration of the project. Specific situations that should be addressed through the use of appropriate signing and channelizing devices in each TTC plan include the following:

1. **Delineating Isolated Hazards**. Delineating isolated hazards (e.g., partially complete guardrail, catch basins, major dropoffs).

2. **Protecting Workers**. Protecting works by separating traffic from an active work site.

3. **Separating Opposing Lanes**. Separating opposing lanes of traffic in confined or detour situations.

4. **Tapers and Transitions**. Tapers and transitions that move traffic from one lane to another, on or off a detour, facilitate a merge, lane narrowing or a one-lane flagging situation.

5. **Delineating Continuous Hazards**. Delineating continuous hazards (e.g., shoulder dropoffs).

6. **Delineating the Traveled Way**. Delineating the traveled way through a work zone when no specific hazards are present. This is often appropriate for low-volume roads where no detour or temporary pavement surface is provided, and traffic must be routed through the work zone. Once the permanent channelizing cues (e.g., delineators, pavement markings) are removed, temporary delineation must be provided, especially for nighttime traffic.

7. **Variable Message Signs**. While TTC devices clearly delineate the path a vehicle is to maneuver through the construction site, changes in the location of these devices during the progress of the project can surprise drivers, especially if a particular phase of construction and its respective TTC devices have been in place for an extended period of time. To alert the driver to changes in the locations, variable message boards can provide added information in advance of the change.

   They can also be placed in advance of the change to alert drivers of a pending change (i.e. warn commuters of a future lane closure, detour or construction activity that may make them want to plan for an alternate route).

   In an age where the motorist feels that they are entitled to as much advance notice of any interruptions to their travel plans, these devices have become very supportive as an outreach device, as well as a safety device.

8. **Temporary Traffic Signals**. While there are few traffic signals on FLH projects, reconstruction in areas with signals sometimes requires that traffic be detoured away from both the existing and future traffic signal location. If, for example, a signalized intersection is completely reconstructed and a temporary detour is used to shift the traffic out of the construction area, temporary signals can be warranted. It may also be more cost-effective to use signals instead of a flagging operation to control traffic for an extended period of time during construction.

   Temporary signals can be installed using embedded poles outside the intersection, with overhead steel cables providing the support of the signal heads, or there can be mobile traffic signals delivered to the site, complete with controllers and interconnects. These compact units are transported similar to variable message boards, and are placed on opposing corners of the intersection to provide both side and overhead signal devices.

8.5.5.5 TTC Barriers/End Treatments

Depending on traffic volume, speed, duration of condition, geometrics and related risk assessment factors, Items one through eight may warrant the use of a temporary concrete barrier. In high-risk situations channelizing devices should not be used alone where a positive barrier is warranted.

8.5.5.6 Traffic Delays

As most of the FLH projects are constructed in congested tourist locations, addressing the delays to the traveler in the TTC is almost as important as the TTC devices themselves. Between the plans and the SCRs, the designer must work with the land manager and local emergency services personnel to establish desirable and acceptable delays to the public during the construction. If only short (15-minute) closures are anticipated, they must still be agreed to with the resource agencies in advance of the advertisement, and clearly conveyed to the contractor through the construction documents.

The TTC plan should clearly identify all restrictions to traffic closures. These restrictions should address activities on holidays or weekends or perhaps between noon on Friday through Sunday nights through an entire summer season. Coordination with the FLH construction personnel on holiday and other shut-downs should also be addressed. Finally, if a closure will be necessary, can it be specified during low-usage times such as midday or evenings? On some projects, the use of incentives or lane rental is an appropriate consideration to limit the impacts from delays.

Occasionally, it is not the time that is the critical factor of a closure, but the impacts of the queued traffic that must be addressed. On some roads, only a few cars will be stopped over a 30-minute closure, with other highways experiencing delays that impact thousands. Working closely with the resource agency over the many variations in the construction restrictions will ensure that confusion and conflicts will be minimized during the construction itself.

8.5.5.7 Emergency Response Considerations

Delays to the traveling public may be unavoidable in order to complete the construction of a project. Delays to emergency services personnel could have severe consequences if these restrictions are not discussed and resolved in advance of the construction activities. Include with the development of the TTC and construction sequencing plan a discussion with local emergency response personnel. Their concerns may be resolved with simple advance notification of any closed traffic operations. In some areas, they may need to mobilize response crews on both sides of the closed roadway to maintain adequate service.

8.5.6 TRAFFIC CALMING

Travelers are often concerned about excessive traffic volumes and speeds on local streets. Local streets are intended to serve the adjacent land use at slow speeds, yet they are often designed so that high-speed travel is accommodated. Well designed traffic calming devices effectively reduce traffic speeds and volumes while maintaining local access to adjacent facilities and turnouts

Public involvement is needed for residents, businesses, planners and engineers to understand the issues and agree with the proposed changes. The benefits of traffic calming, especially for pedestrians and bicyclists include:

- reduced traffic speeds and volumes allow bicyclists to share the road with vehicles;
- quieter streets and increased ease of crossing enhance the pedestrian environment;
- lower traffic speeds increase safety (high speeds are responsible for many pedestrian fatalities); and
- in park settings, lower traffic speeds enhances the visitor experience at a natural setting.

8.5.6.1 Managing Speeds

Managing traffic speeds can be accomplished through physical constraints on the roadway or by creating an “illusion of less space.” Motorists typically drive at a speed they perceive as safe; this is usually related to the road design, especially available width.

One way to achieve the lower speed is to provide various physical constraints. The following are some examples:

1. **Narrow Streets or Travel Lanes**. Narrow cross sections can effectively reduce speeds, as most drivers adjust their speed to the available lane width. Narrow streets also reduce construction and maintenance costs.

2. **Speed Humps** (not speed bumps). If well designed, speed humps allow a vehicle to proceed over the hump at the intended speed with minimal discomfort, but driving over the hump at higher speeds will rock the vehicle. The hump is designed with a reversing curve at each end, and a level area in the middle long enough to accommodate most wheelbases.

3. **Chokers** (curb extensions). Chokers constrict the street width and reduce the pedestrian crossing distance.

Another means to reduce speeds is to provide the illusion of limited space. Examples of this technique include:

1. **Creating Vertical Lines**. By forcing some natural or barrier elements closer to the roadway edge, the roadway will appear narrower than it is. This can be accomplished with longitudinal barriers, curbs or trees and landscaping.

2. **Coloring or Texturing Bike Lanes**. Drivers see only the travel lanes as available road space, so the roadway appears narrower than it is. Painting the road surface is expensive; lower-cost methods include:

   - paving travel lanes with concrete and bike lanes with asphalt, or the reverse;
   - slurry-sealing or chip-sealing the roadway and not the bike lanes; and
   - incorporating dyes into concrete or asphalt.

3. **Chicanes**. By alternating on-street parking, landscaping or other physical features from one side of the road to the other, the driver does not see an uninterrupted stretch of road. The roadway width remains adequate for two cars to travel.

8.5.6.2 Roundabouts/Roadway Encroachments

Roundabouts are a common form of intersection control used throughout the world. However, many State and local agencies throughout the United States have been hesitant to install roundabouts due to a lack of objective nationwide guidelines on planning, performance and design.

Roundabouts require strict conformance to standard practice to ensure safe, optimal operation and this scattered approach to design can lead to inconsistencies at a national level, which are consequential in terms of driver expectation and safety. Refer to FHWA publication *Roundabouts: An Informational Guide*.

Roundabouts: An Informational Guide addresses the following topics:

- definition of a roundabout and what distinguishes roundabouts from traffic circles;

- methodology for identifying appropriate sites for roundabouts and the range of conditions for which roundabouts offer optimal performance;

- methodology for estimating roundabout capacity and delay;

- design principles and standards to which roundabouts should conform, including applicable national standards (e.g., the AASHTO *Policy on Geometric Design of Highways and Streets*, the *Manual on Uniform Traffic Control Devices)*;

- consideration for all modes, including heavy vehicles, buses, fixed route transit, bicycles, pedestrians and emergency vehicles;

- guidelines for operational features (e.g., signing, pavement markings, illumination, landscaping); and

- public acceptance and legal issues associated with roundabouts.

8.5.7 EVALUATION OF THE DESIGN FOR WEATHER CONDITIONS

Most of the time, a roadway surface is dry and will allow a vehicle to respond in a predictable manor while the driver is negotiating stops, curves and lane changes. The engineer should also take into account what will happen to the roadway surface during inclement weather activities as well, especially if these activities recur every season. Vehicles traveling on impaired road surfaces often lose traction. With a loss of traction comes a loss of control of the vehicle. The problem is exacerbated when out-of-control vehicles on impaired roads frequently end up crossing the centerline and colliding head-on with oncoming vehicles. The oncoming vehicle has limited defensive capabilities as their tire friction and opportunity to respond is also impaired.

The following Sections discuss recurring activities and some precautions that should be considered as the design is developed.

8.5.7.1 Skid Resistance

During field reviews of the surface, if any patch of slick or damaged asphalt occurs, this will prohibit proper friction between the vehicles tires and the roadway during inclement weather. The surface should be repaired and covered with a friction course or wearing course.

8.5.7.2 Black Ice

Black ice is typically formed due to snow melt running across the roadway surface during the day, and freezing on the roadway or bridge surface at night. Some of this can only be mitigated with proper snow maintenance activities (e.g., plows pushing the snow completely off of the roadway surface and into a ditch). As a designer, there are elements of design that can minimize the occurrence of snowmelt from crossing the roadway. These include:

- In areas where there is no ditch, consider the installation of concrete barriers to prevent runoff from reaching the roadway surface.
- Clear trees sufficiently away from the roadway, ensuring no shadows are present on the pavement that would retain ice on the roadway in spots rather than melting and draining away.
- Avoid abrupt horizontal curves in areas where ice may form, especially on bridge decks, as these surfaces stay frozen the longest.

8.5.7.3 Snowpack and Snow Storage

To prevent black ice from occurring, there must be adequate storage for plowed snow to be contained off of the roadway prism while it melts. The designer must consider not only the capacity to handle the melted water in the runoff, but the area required to contain the snow mass while it melts. Finally, if the slopes adjacent to these storage areas can be cleared sufficiently to allow late-day sun, the site would benefit from quicker melting times.

8.5.7.4 Fog

Research continues on providing direction for when the following should be installed to mitigate fog conditions:

- RPMs,
- rumble strips, and
- profiled striping.

8.5.7.5 Bridge Conditions

Discussions/Suggestions for these sections are still pending:

- *runoff,*
- *runoff containment of haz spills,*
- *sags, and*
- *horizontal curves in snow climates*.

8.5.7.6 Barrier and Bridge Rail Considerations

Discussions/Suggestions for these sections are still pending:

- *permeable vs. non-permeable barrier in snow areas,*
- *plow conditions, and*
- *maintaining shy distance.*

8.6 TRAFFIC ANALYSIS

A traffic analysis is an evaluation of the roadway's projected demand and the effects of that demand on the capacity of either the existing or proposed facility.

The analysis of the traffic on a transportation facility is a fundamental concern of transportation engineering. There are essentially two components of traffic analysis:

1. **Demand**. The traffic load that will use the facility (Projected Traffic Volumes).
2. **Supply**. The ability of the roadway to handle the traffic load or the roadway's Capacity.

8.6.1 TRAFFIC DEMAND

One of the real complexities of the transportation problem is the inability to accurately predict and control the level of demand for the system or the service. Transportation demand is generally related to social and economic influences. Transportation demand generally relates to commuters or visitors that result in other activities that may eventually lead to a physical load (e.g., the passage of vehicles over a section of roadway or a street).

A multitude of factors can contribute to the level of transportation demand, and are summarized in the following Sections.

8.6.1.1 AADT

The foundation of demand is based on the current traffic counts of a facility. The measurement of traffic is generally considered to be in terms of the flow of vehicles. The flow is typically expressed in terms of vehicles per unit of time.

Some commonly used units of measurement for traffic flow are vehicles per day, vehicles per hour, passengers per day, etc. The common measurements of traffic flow are vehicles per day (veh/day) or vehicles per hour (veh/hr). A good reliable indicator of the general level of traffic activity on a street or a roadway is the Average Annual Daily Traffic (AADT). This is the mean daily traffic at a highway location averaged on an annual basis. If the facility is not open all year long, then traffic volumes will only be described in seasonal averages.

8.6.1.2 Seasonal Variations

Many facilities have varying traffic volumes throughout the year. These seasonal fluctuations can vary greatly, but they are generally very predictable. Seasonal peaks are particularly important to recreational facilities. To make adequate projections, traffic counts must be acquired throughout the year at regular intervals. These counts will generate a pattern that can be used to project the Average Daily Traffic (ADT) for any given season.

8.6.1.3 Peak Hour/Design Volumes

AADT counts (collected for continuous 24-hr periods) are the typical source of traffic volume information. Designing the facility to meet the average daily traffic can result in significant delays during the higher use periods. The Design Hourly Volume (DHV) has become the standard for estimating the typical traffic loads during the day. It is based on the 30th highest hour of the year. The highest hourly volumes that occur in a given day are called the Peak Hourly Volume. This volume can be determined using Equation 8.6(1):

$$PHV = AADT \times K \times D \qquad \text{Equation 8.6(1)}$$

Where:

PHV = Peak Hour Directional Volume

AADT = Average Annual Daily Traffic (vehicles per day)

K = Peak-Hour Factor (the proportion of vehicles traveling during the peak hour expressed as a decimal)

D = Directional Split Factor (the proportion of vehicles traveling in the peak direction during the peak hour, expressed as a decimal)

If no specific information is provided, the typical K factor for a rural facility is 12 to 15 percent, and 10 to 12 percent for an urban facility.

8.6.1.4 Trends (Past and Projected)

Future Discussion Topic:

- *Local Growth/Population Trends*
- *Park Visitor Attendance History/Projections*

8.6.1.5 Classifications

Future Discussion Topic. A general discussion on the various types of roadway classifications will be added here.

8.6.1.6 Traffic Factors (K, D, T)

Several factors are used to evaluate the traffic flow. The three most common factors provided include the Peak-Hour Factor (K), the Directional Split Factor (D) and the percentage of trucks using the facility (T).

The K- and D-factors are usually determined on the basis of regional or route-specific characteristics. Generally, the K-factor ranges from 0.07 to 0.15 while the D-factor ranges from 0.50 to 0.65 in urban and suburban areas. If these factors are unknown or cannot be easily determined, a default K-factor of 10 percent may be assumed (expressed as 0.10), and a default D-factor of 55 percent may be used (expressed as 0.55). Note also that for one-way streets, the D-factor becomes 1.0 since 100 percent of the traffic is traveling in the same direction.

8.6.1.7 Turning Movements

Reserved

8.6.1.8 Speed and Delay Data

Reserved

8.6.1.9 Conflict Study Data

Reserved

8.6.2 HIGHWAY CAPACITY

The method used for describing and determining capacity and traffic operating conditions is outlined in the *Highway Capacity Manual* (HCM).

8.6.2.1 Level of Service

Level of Service (LOS) is defined as a qualitative measure of operational conditions within a traffic stream and the perception by motorists. Six levels of service, LOS A through LOS F, are used to designate different operating conditions in terms of such factors as speed, travel time, freedom to maneuver, traffic interruptions, comfort, convenience and safety.

8.7 TRAFFIC DESIGN

8.7.1 SIGNING AND DELINEATION

The *Manual on Uniform Traffic Control Devices* (*MUTCD*) is the national standard for signing, signalization, channelization and pavement markings for all highways in the United States. *FHWA Standard Highway Sign Book* and the *NPS Sign Manual* both provide additional design criteria, methods and charts for design.

All traffic control devices shall be in accordance with the MUTCD. Compliance with the requirements of the MUTCD for all traffic control devices is mandatory and includes the following:

- use;
- placement;
- uniformity;
- maintenance;
- color;
- size;
- shape;
- legend;
- retroreflectivity; and
- removal, when not applicable.

The main message of the MUTCD is the importance of uniformity. Substantial adherence to the *MUTCD* is required on all public roads. However, some owner agencies have supplements or have developed similar manuals (e.g., the *NPS Sign Manual*), that must also be considered when designing and constructing roads under NPS jurisdiction. The *Traffic Control Devices Handbook* provides a compendium of traffic control system technology.

Highway users are dependent on traffic-control devices (i.e., signs, markings, signals) for information, warning and guidance. Uniform high-quality devices are important for the safe, efficient use and public acceptance of any highway regardless of the roadways excellence in width, alignment and structural design.

Any traffic control device should meet all the following requirements:

- fulfill an important need;
- command attention;
- convey a clear, simple meaning;
- command respect of road users; and
- give adequate time for proper response.

It should be noted that law must sanction devices controlling or regulating traffic.

The following aspects should be carefully considered in order to maximize the ability of the traffic control device to meet the five requirements listed above:

- design,
- placement and operation,
- maintenance, and
- uniformity.

Consideration should be given to these principles during the design stage to ensure that the required number of devices can be minimized and properly placed.

8.7.1.1 Signing

The above-cited references provide the designer with the information required to properly select the appropriate signing. Sign supports should be designed in accordance with the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals*. Owner agency practice, in accordance with the above standards, may dictate the types of materials to be used. Sign supports and luminaries located within the clear zone shall meet the requirements of *NCHRP 350*. Also, see the FHWA Roadside Hardware website.

Designers should be aware that the NPS-52 *Traffic Control Guideline* requires each park to have an established sign plan. These plans should be reviewed together with crash statistics and any available safety studies to ensure continued appropriateness whenever additional construction work takes place. Similar plans may exist on specific routes with other owner agencies and should likewise be requested and reviewed.

The authority for regulatory signing rests with the maintaining/regulating agency. Likewise, the client agency may have specific concerns regarding warning or informational signs. The designer's responsibility is to identify all signs required and review them with the appropriate agencies during project development.

Finally, designers that develop site-specific signs must evaluate if the lettering is large enough to be both visible and legible at the distance and speed that the user is traveling. Lettering sizes varies with the design speed. This information is found in the *MUTCD*, *Standard Highway Signs* or *NPS Sign Manual*.

8.7.1.2 Pavement Markings

Pavement markings have definite and important functions to perform in a proper scheme of traffic control. In some cases, they are used to supplement the regulations or warnings of other devices (e.g., traffic signs, signals). In other instances, they are used alone and produce results that cannot be obtained by the use of any other device. In these cases, they serve as a very effective means of conveying certain regulations and warnings that could not otherwise be made clearly understandable.

Pavement markings have definite limitations. They can be obliterated by snow, may not be clearly visible when wet and may not be very durable when subjected to heavy traffic. In spite of these limitations, they have the advantage, under favorable conditions, of conveying warnings or information to the driver without diverting the driver's attention from the roadway.

8.7.1.2.1 General Application

Each standard marking shall be used only to convey the meaning prescribed for it in the *MUTCD*. Before any new paved highway, surfaced detour or temporary route is opened to traffic all necessary markings must be in place.

Remove or obliterate markings no longer applicable, or which may create confusion in the mind of the motorist, as soon as practicable. Painting over markings is not an acceptable method of obliteration. Markings must be retroreflective.

All markings must be placed in accordance with the *MUTCD*.

8.7.1.2.2 Pavement Marking Materials

The standard material to be used for pavement markings is an applied paint with reflective beads. All other pavement-marking materials are considered to be upgraded materials. To upgrade, consideration must be given to material performance, material cost, traffic volume and type, climatic conditions, availability of materials and installation equipment (both for initial installation and maintenance). Only when an upgraded material is established to be more cost-effective than the standard material can the upgraded material be used. The following guidelines may be used for upgrading the striping material in lieu of an economic evaluation:

1. **Epoxy and Polyester Materials**. Epoxy thermoplastic (ETP), epoxy and polyester materials may be specified for centerlines, lane lines and edge lines under any of following conditions:

    - the average daily lane volume is in excess of 1000;

    - because of environmental, traffic or climatic conditions, it is necessary to restripe with paint two or more times a year, or epoxy every two years; or

    - the location is not proposed or scheduled for sealing or resurfacing within the next three years.

2. **Thermoplastic and Preformed Plastic Materials**. Additionally, thermoplastic and preformed plastic type materials may be allowed for centerlines, lane lines and edge lines when one of the following conditions are met:

    - the average daily lane volume is in excess of 5000;

- the location is not proposed or scheduled for sealing or resurfacing within the next five years; or

- the pavement markings are considered critical (e.g., intersections, lane drops).

Epoxy thermoplastic, epoxy or polyester materials may be specified under lower traffic conditions where there is a need to emphasis transitions, channelization or special markings (e.g., stop lines and crosswalks). Before specifying these materials, additional consideration should be given to justify the added costs of these materials if it will be less than three years before the pavement is scheduled for sealing or resurfacing.

8.7.1.3 Roadway Delineation

The appropriate type of raised pavement markings and/or snow plowable recessed low profile markers should be considered for the following:

- intersection channelization,
- directional left-turn lanes,
- high hazard/crash locations,
- areas of frequent inclement weather,
- combined installations with preformed plastic markings where no overhead lighting exists, and
- gore areas and approaches to deceleration lanes.

Pavement striping tape may be specified as a temporary measure when conditions do not permit painting or while the highway is under construction.

8.7.1.4 Special Pavement/Surface Treatments

8.7.1.4.1 Longitudinal Rumble Strips

Run-off-the-road crashes cause one-third of all traffic fatalities and two-thirds of those crashes occur in rural areas. The main causes of run-off-the-road crashes are driver inattention. In 1995, the crashes caused by drivers asleep at the wheel caused 1500 deaths and 71,000 injuries. Noise and vibration produced by shoulder rumble strips are effective alarms for drivers who are leaving the roadway. They are also helpful in areas where motorists battle rain, fog, snow or dust.

Longitudinal rumble strips are raised or grooved patterns on the roadway shoulder that provide both an audible warning (rumbling sound) and a physical vibration to alert drivers that they are leaving the driving lane. In addition to warning inattentive drivers, rumble strips help drivers stay on the road during inclement weather when visibility is poor. Some States paint stripes over the rumble strips (i.e., rumble stripes) to make them visible.

There are two types of longitudinal rumble strips. The most common type of strip is the continuous shoulder rumble strip. These are located on the road shoulder to prevent roadway departure crashes on expressways, interstates, parkways and two-lane rural roadways that have high numbers of single-vehicle crashes. Centerline rumble strips are used on some two-lane rural highways to prevent head-on and sideswipe type collisions.

8.7.1.4.2 Profile Striping

This is a method of providing lane delineation using a contoured striping technique. The striping material is applied to produce a pattern of raised material or bumps in the striping, resulting in a similar benefit as longitudinal rumble strips without the need to damage the roadway surface. This type of application only works in environments where plowing the roads is not required. However, this material may be applied in snow areas if the material is placed in a recessed groove in the pavement.

8.7.1.4.3 Transverse Rumble Strips

Transverse Rumble Strips are ground-in strips located in or across the travel lanes that often precede intersections, especially dangerous ones. They are typically installed in groups of joints across the travel lanes, and the separation between these groups is reduced as the driver approaches the intersection or feature being addressed.

8.7.1.4.4 Button Treatments

Similar to longitudinal or transverse rumble strips, raised pavement markers or buttons are used in place of ground-in strips or joints. This type of application only works in environments where plowing the roads is not required.

8.7.2 INTERSECTION APPROACH DESIGN

Refer to Chapter 9, Section 9.3.14 for guidance on intersection design.

8.7.2.1 Left Turn Lanes

Refer to Chapter 9, Section 9.3.14.6.

8.7.2.2 Right Turn Lanes

Refer to Chapter 9, Section 9.3.14.7.

8.7.3 AUXILIARY LANE DESIGN

Refer to Chapter 9, Section 9.3.9.2.

8.7.3.1 Weaving Requirements

Refer to the *Highway Capacity Manual* for guidance on the operation and analysis of weaving sections.

8.7.3.2 Climbing Lanes

Refer to Chapter 9, Section 9.3.9.7.

8.7.3.3 Passing Lanes

Refer to Chapter 9, Section 9.3.9.8.

8.7.3.4 Pullouts

Refer to Chapter 9, Section 9.3.9.9.

8.7.4 PEDESTRIAN FACILITIES

Refer to Chapter 9, Section 9.3.16.

8.7.4.1 ADA Requirements

Refer to Chapter 9, Section 9.3.16.3.

8.7.5 BICYCLE FACILITIES

Refer to Chapter 9, Section 9.3.17.

8.7.6 PARKING FACILITIES

Refer to *ITE Guidelines for Location and Design of Parking Facilities*, 1994.

8.7.7 TRAFFIC SIGNALS

Because most FLH Program work is in rural areas, there is seldom a need for signalized intersections or advanced traffic control systems (e.g., ramp monitoring on controlled access facilities). However, temporary signals are an effective tool for managing traffic where long-term one-lane operations are required for bridge rehabilitation or similar work. It is important to obtain all available information on traffic and pedestrian volumes, turning movements, crash data and the length of a one-lane segment (e.g., frequency, location, type, speeds) in order to design the temporary signal phasing and timing.

The design of temporary traffic signal devices and warrants for their use are covered in the *MUTCD*. Consult additional reference sources when designing signalized intersections and other traffic control systems not covered by the *MUTCD*. The *Traffic Control Devices Handbook* provides the fundamental procedures for proper analysis and design of traffic control systems as well as the *Highway Capacity Manual*.

Traffic control signals are devices that control vehicular and pedestrian traffic by assigning the right-of-way to various movements for certain pre-timed or traffic-actuated intervals of time. Traffic control signals are one of the key elements in the function of many urban streets and of some rural intersections. The planned signal system for a facility should be integrated with the design to achieve optimum safety, operation, capacity and efficiency. Careful consideration should be given in plan development to intersection and access locations, horizontal and vertical curvature, pedestrian requirements and geometric schematics to ensure the best possible signal progression, speeds and phasing. In addition to the initial installation, future needs should also be evaluated.

Owner agencies or State highway agencies are good sources for design assistance, particularly in the area of equipment compatibility and electrical design.

8.7.8 ILLUMINATION

Reserved

8.7.9 ITS

Reserved

8.8 *RESERVED*

8.9 *RESERVED*

8.10 DIVISION PROCEDURES

This Section is reserved for the Federal Lands Highway Division in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

8.10.1 EFLHD PROCEDURES

Refer to the EFLH Division Supplements.

8.10.2 CFLHD PROCEDURES

Refer to the CFLH Division Supplements.

8.10.3 WFLHD PROCEDURES

Refer to the WFLH Division Supplements.